EXPERIMENTAL OBSERVATIONS OF THE TORSIONAL BEHAVIOR OF OPEN END SPUN YARNS

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EXPERIMENTAL OBSERVATIONS OF THE TORSIONAL BEHAVIOR OF
OPEN END SPUN YARNS

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SUMMARY

Studies by Lord and others indicate that the structure of yarns spun on open end spinning equipment is significantly different from the structure of yarns spun on conventional ring frames. As a first approximation, it has been concluded that open end spun yarns have a radial twist distribution whereas ring spun yarns have a uniform level of twist throughout the yarn cross section. Accordingly, it is expected that the torsional properties of the yarns (torque response to yarn tension and torsional rigidity) differs significantly from the properties of comparable ring spun yarns.

This study is concerned with the experimental characterization of the torsional properties of open end spun yarns. Both cotton and cotton/polyester yarns spun on a laboratory device will be examined. Commercially produced yarns will be tested.

Measurements of yarn torque will be made on a laboratory torsion wire instrument. This instrument is equipped with a device to uptwist yarn specimens while they are mounted to determine torsional rigidity. Lastly, weights can be applied to the specimens to determine the torque-tension gradient of the yarn.

CHAPTER I

INTRODUCTION

Open end spun (OES) yarns are different structurally when compared to ring spun yarns. For instance, the degree of fiber migration is lower.[1,2] This migration may be ignored if one considers that a yarn is an infinitely long length of short connected segments each containing helically-wound fibers. For most textile structures, this helical geometry is either expressed as twist per unit length or surface helix angle. The widely known expression which relates surface helix angle to yarn twist is given as:

$$\mathrm{TAN}\theta=2\pi rt$$

where θ=surface helix angle

r=radial distance between filaments and the center of the yarn

t=yarn twist per unit length

The value of t does not usually vary with the radius for ring spun yarns. In ring spun yarns, twist is inserted in a bundle of fibers whose cross-sectional shape prior to twisting is that of a ribbon or a flattened rod. The geometric constraint imposed by the roller nip results in positive strain for the outside fibers while the central or core fibers attempt to go into compression. Hearle[3] has pointed out that this differential condition of strain leads to migration, that is, the fibers try to arrange their paths so that the yarn takes a lower strain energy state.

Recent experimental investigations indicate that this is not the case for OES yarns.[4] Lord has shown that the yarn torsion essentially varies indirectly with yarn radius, i.e. yarn torsion is maximum in the center of the yarn. Moreover, Lord suggests that OES yarns consist of three concentric layers of fibers: core, outer, and wrapper. The core layer has a geometry similar to that found in ring spun yarns. This is evident, for the conditions of formation of the core are quite similar to those conditions present during ring spinning. There is a significant degree of fiber migration because of the differential fiber strains imposed as the fibers are forced to assume varying path lengths and this condition of strain causes significant normal pressure between fibers and the core. Accordingly, the amount of yarn torsion in the core is essentially constant. This is not the case for the outer fibers. It has been observed that the outer fibers actually slip by each other during yarn formation.[4] It can be expected therefore, that this layer has less torsion than a corresponding layer for a ring spun yarn. The third layer, the wrapper (ringers) have a very high helix angle and appear as bands which surround the loose outer fibers. It has been theorized that these ringers come from loose fibers in the rotor chamber being grabbed by the fiber bundle at the point of twist insertion.[4] They contribute little or nothing to the yarn strength.

Yarns are characterized in terms of linear density and degree of torsion.

> Many methods of twist measurement rely on parallelism of the fibers at one state in the measurement process, but with the differential twist structure described it is impossible to achieve such parallelism of the fibers in OES yarns. Since radial twist gradients are likely to vary from yarn to yarn, there is a problem of evaluating test results. In many cases, the yarn is untwisted and then reverse twisted until the original length is reestablished; in this way, it is possible to determine the twist level. Even with ring yarns, it is doubtful if the number of reverse turns equals the original number (which is the underlying assumption) because of structural changes caused by the test procedure. With OES yarns the proposition becomes more doubtful and again there seems to be the possiblility of greater variation. Owing to the difficulties in twist measurement, it is becoming the practice with OES yarns to quote the machine twist calculated from the relevant twist gear and machine constant. This ignores fiber slippage which takes place at the yarn formation point within the rotor. This slippage enables the differential twist pattern to occur and is likely to cause the machine twist to be greater than the actual mean twist.[5]

Yarn torque is recognized as coming from three sources; torque due to: fiber tension, fiber torsion, and fiber bending.[6,7] Investigations into the origin of yarn torque have been conducted for ring spun and textured yarns.[6,8,9,10] These studies have been based on the assumption of an idealized helical yarn geometry, linear fiber elasticity, and uniform twist distribution across the radius of the yarn cross section. As stated earlier, the uniformity of yarn twist across the yarn radius is not present for open end spun yarns. Therefore, one cannot simply determine the torsional behavior of open end spun yarns from the analyses used for ring spun or textured yarns. Any attempt to quantify the torsional behavior of open end spun yarns must first be concerned with experimental characterization of these yarns. This study is concerned with this characterization and apart from being purely an academic endeavor, there is important commercial significance to this study.

Yarn formation during open end spinning takes place as fibers, on a rotating cup, are withdrawn through a fixed doffing tube mounted at the center and coaxial to the cup. (Figure 1) It is the action of extracting a parallel bundle of fibers away from the rotating cup which causes twist to be inserted in the yarn. Stated another way, when one end of the yarn rotates relative to the other end and there is a break in the fiber flow prior to twist insertion, real twist is generated. This twist propagates back to the cup wall and provides the cohesion necessary to allow the fiber bundle to be lifted from the rotor wall.

The interaction of the yarn-cup forces is of considerable importance to the OES process. For example, if the local yarn tension approaches the ultimate yarn strength, there is a strong possibility that the yarn will break and

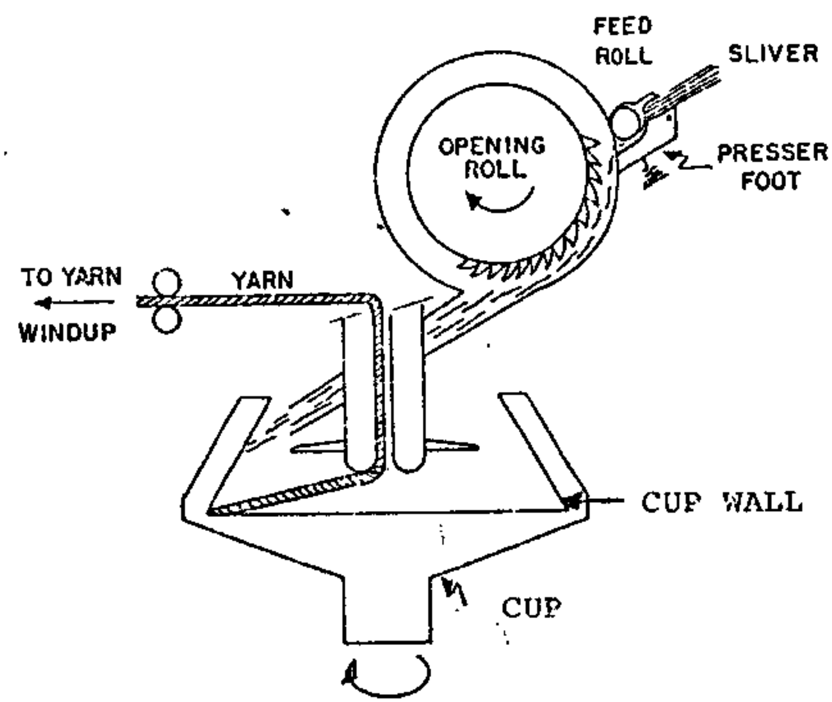


Figure 1. Principles Of Open End Spinning

result in a loss of spinning efficiency. The point where the yarn is formed also is the location of torque generation for the OES system. That is, a combination of yarn geometry, cup geometry, fiber to cup friction and centrifugal forces, determine the torque generation capability of the process. If this capability is about equal to the yarn torque which might result if the actual yarn twist were to equal machine twist, then it should be obvious that the potential for dynamic instability or periodic rotational slippage would be present. Also, if the required yarn torque is significantly higher than the torque generation capability of the cup, continual slippage will occur and the system will not operate efficiently. One must have an idea as to what the torque in an open end spun yarn is during formation to determine if the above mentioned problems exist.

If the yarn does indeed slip during processing it is necessary to determine if the slippage causes either a concentrated twist reduction at the point of twist insertion or rather spreads out over the already formed yarn. Backer et al have shown the significance of twist slippage during texturing and the resulting negative effect on textured yarn quality; twist slippage results in concentrated regions of real twist in the heretofore false twist yarn.[11]

This thesis is concerned with determining if similar behavior (i.e. torsional rigidity) exists in the open end spinning threadline. This investigation also is directed towards determining the residual yarn torque in a yarn when it is relieved of tension. This torque serves to characterize the twist liveliness of OES yarns, for the greater the residual torque, the more apt the yarn is to snarl or kink during fabric formation processes (i.e. weaving and knitting) when yarn tension is relieved hastily. A similar pair of commercial open end spun yarns and ring spun yarns were compared to determine if any significant difference in their torsional behavior exists. These yarns had similar counts, twist multiples, and fiber content.

CHAPTER II

EXPERIMENTAL PROCEDURE AND INVESTIGATION

II.1. Scope of Experimental Investigation

The characterization of the torsional behavior of OES yarns is based on the determination of the torsional rigidity, the torque response to tension, and the inherent yarn torque due to fiber bending and fiber torsion. These experimental determinations serve as the justification of the experimental work presented in this study. Torsional rigidity of OES yarns is determined by measuring the incremental addition or subtraction of yarn torque due to either incremental uptwisting or downtwisting of a yarn specimen. Torque response to yarn tension is determined by measuring the incremental addition of yarn torque which results from the incremental addition of yarn tension. Lastly, the inherent yarn torque due to both fiber bending and fiber torsion is determined by extrapolating the torque-tension response to zero tension.

The process and material parameters investigated were the following; rotor speed, combing roller speed, yarn number and fiber type. The selection of these parameters was based on their being similar to those presently chosen commercially.[12] A list of the combination of those parameters is given in Table 1.

Table 1. Yarn Characteristics

Identification Code Number	Rotor Speed RPM	Combing Roller Speed RPM	Yarn Number Cotton Count	Yarn Number Denier	T.P.I.	T.M.	Fiber Type
1	25593	5000	14.3	373	11.7	3.11	cotton
2	25593	6000	14.0	380	11.6	3.11	cotton
3	25593	7000	13.8	385	11.6	3.13	cotton
4	25593	8000	14.0	380	11.6	3.09	cotton
5	25593	9000	14.3	371	11.7	3.09	cotton
6	28875	5000	16.4	324	13.2	3.24	cotton
7	28875	6000	13.8	387	12.2	3.30	cotton
8	28875	7000	16.5	322	12.7	3.13	cotton
9	28875	8000	16.1	330	13.0	3.25	cotton
10	28875	9000	16.5	323	13.3	3.27	cotton
11	31500	5000	16.3	327	13.9	3.44	cotton
12	31500	6000	13.9	384	14.0	3.77	cotton
13	31500	7000	13.8	387	14.3	3.87	cotton
14	31500	8000	13.7	389	12.6	3.42	cotton
15	31500	9000	13.7	387	14.1	3.81	cotton
16	28875	5000	13.5	393	12.6	3.44	cotton
17	28875	7000	14.0	380	12.5	3.35	cotton
18	28875	8000	14.3	371	12.8	3.38	cotton
19	28875	9000	13.8	385	12.7	3.43	cotton
20	31500	5000	14.5	366	14.0	3.68	cotton
21	28970	7000	14.1	377	13.8	3.68	35% cot/65% poly
22	28970	8000	14.0	379	14.6	3.89	35% cot/65% poly
23	28970	9000	14.3	373	14.2	3.76	35% cot/65% poly
24	31500	7000	16.6	321	14.3	3.51	35% cot/65% poly
25	31500	7000	14.4	368	14.0	3.68	35% cot/65% poly
26	31500	8000	14.0	380	14.3	3.83	35% cot/65% poly
27	31500	9000	16.7	319	14.3	3.51	35% cot/65% poly
28	31500	9000	14.0	381	13.8	3.70	35% cot/65% poly
29	32913	8000	16.1	331	14.1	3.51	35% cot/65% poly
30	32913	8000	14.1	378	14.0	3.74	35% cot/65% poly
31	32913	9000	16.2	329	14.5	3.62	35% cot/65% poly
32	32913	9000	14.5	366	15.1	3.96	35% cot/65% poly
33	32913	7000	14.1	378	14.3	3.82	35% cot/65% poly
34	commercial ring spun		9.6	552	11.1	3.57	cotton
35	commercial open end spun		9.7	547	12.0	3.85	cotton

II.2. Equipment and Materials for EXPERIMENTAL INVESTIGATION

II.2.a. Open End Spinning Frame

The laboratory OES yarns used for this experimental investigation were spun on a laboratory open end spinning frame consisting of a Toyoda BD200 spinning head. This open end spinning unit has been designed so as to allow independent changing of combing roller speed, rotor speed, and take-up roller speeds.

II.2.b. Materials

The studied yarns were spun from one of two fiber stocks; a 100% cotton sliver and a 65%/35% polyester-cotton blend sliver. The 100% cotton 65 grain sliver consisted of 1 1/16→1 1/32 inch, 50%/50% blend of American Upland Sawginned Memphis Strict Low Middling (SLM) and Memphis Low Middling (LM) fiber. The micronaire reading was 4.4-4.7 and the digital fibrograph reading was 1.05 to 1.10. The 65% polyester/35% cotton 65 grain sliver consisted of the same cotton stock as the 100% cotton sliver blended with a 1½ inch polyester staple. The two commercial 100% cotton yarns were spun from the same cotton stock as the laboratory yarns.

II.2.c. Twist Tester

An Alfred Saurer Company twist tester was employed using a center loading variable tensioning device at a guage length of ten (10) inches in accordance with the procedure set forth in ASTM Method D1422.

II.2.d Torsion Wire Balance

A torsion wire balance or a comparator torsion tester was constructed to measure torque in threadline segments obtained from both the laboratory open end spinning frame and the commercial frame. A schematic diagram of the instrument is illustrated in Figure 2. The apparatus consists essentially of three elements in series; a calibrated Chromel A reference wire, a viscous oil damper, and a mirror mounted on the test specimen clamp. The shear modulus of Chromel A wire, measured by Mr. James Donovan of FRL, was 12.0×10^6 lbs/in^2.[13] This torsional rigidity of the reference wire is considerably larger (~1000 times) than that of the test specimen. This insures that the torsional yield strain of the wire is not exceeded during measurements of yarn torque. The viscous oil damper was used to reduce the effect of settling transients and hence, to hasten the measuring procedure. The mirror-optical system employed to determine the torsional displacement of the reference is shown in Figure 3. The mirror mounted on the test specimen clamp deflects α radians when torque is applied to the clamp. If the mirror is focused on a meter scale at a fixed distance, D, from the mirror reflective plane and the perpendicular distance of that plane to scale is known, one can simply determine the deflection angle, α, through triangulation, such that,

A. INSTRON MOUNT
B. STARRET "A" PIN VICE
C. CHROMEL "A" REFERENCE WIRE
D. OIL DAMPER
E. MIRROR, FLAT PLANE
F. INSTRON "A" CLAMP, TEST SPECIMEN CLAMP
G. SPECIMEN MOUNT
H. YOKE
I. PROTRACTOR
J. TORSION WIRE YOKE BASE
K. STABILIZING WEIGHT
L. INSTRON TESTER, TABLE TOP MODEL

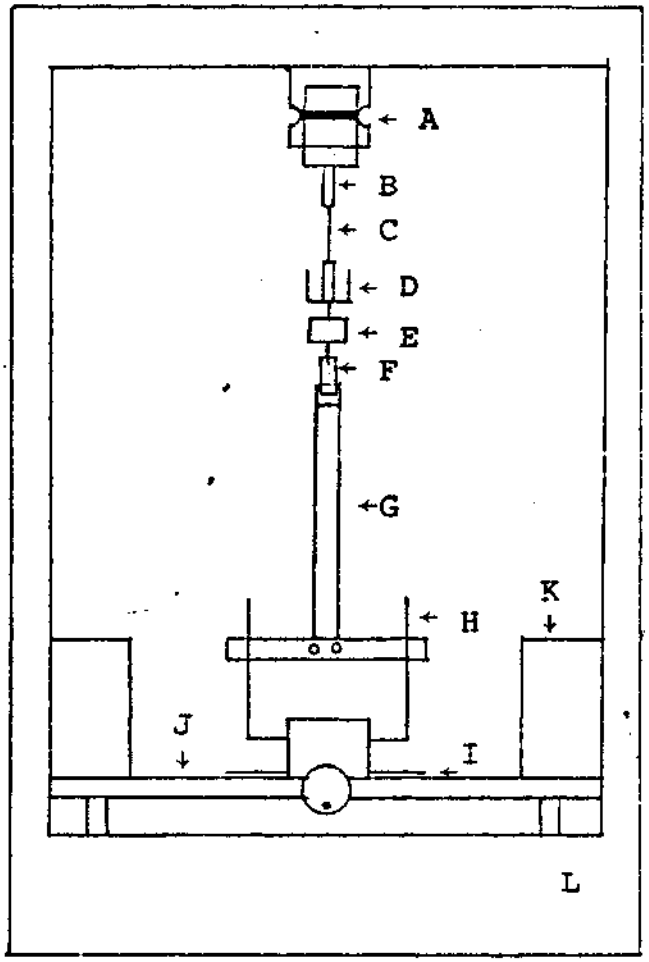


Figure 2. Torsion Wire Balance

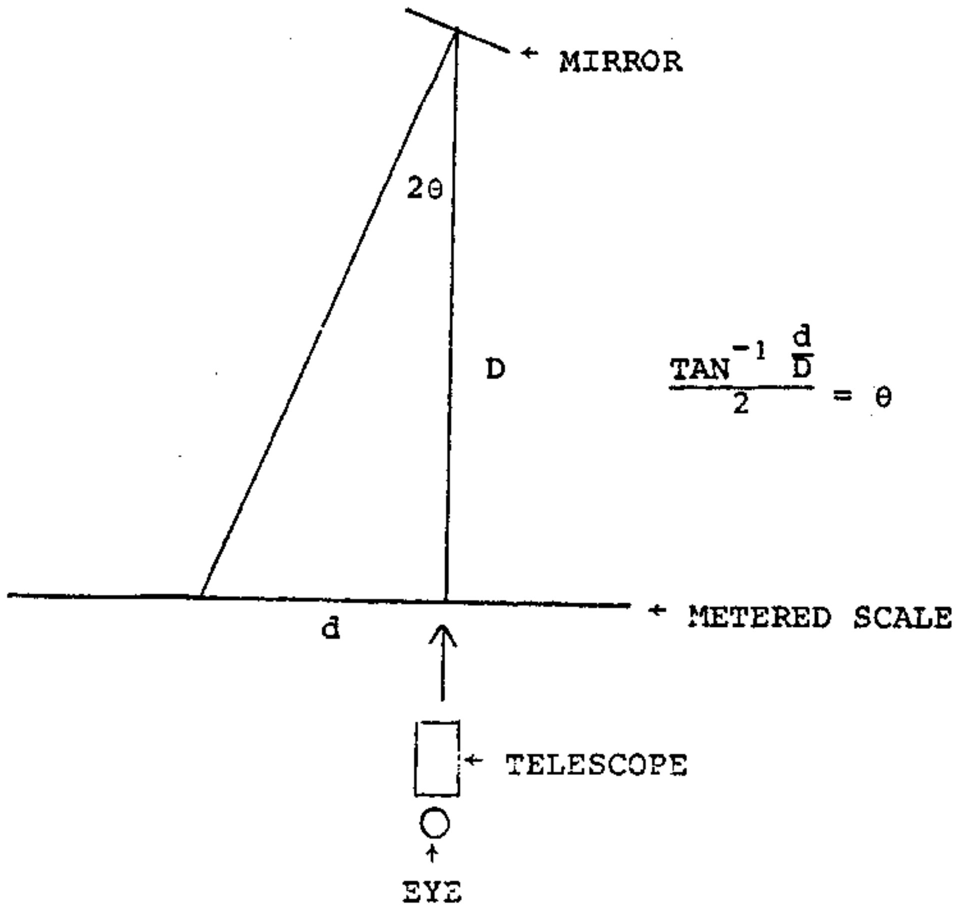


Figure 3. Optical System

$\alpha=\frac{d}{2D}$, d=Linear Torsion Pendulum scale deflection, D=Distance of Torsion Pendulum scale from mirror

$$\alpha=\frac{d}{2D}$$

where d=Linear Torsion Scale Deflection

D=Distance of Torsion Pendulum scale from mirror

The yarn torque is related to the moment of torsion of the Chromel A reference wire and the angular deflection produced by the system. At equilibrium,

Yarn Torque, M=wire torque, M_ω

The moment of torsion of the wire, M , is given by:

$$M_o=\frac{M_\omega}{\alpha}$$

and therefore, $M=M_o\alpha$

The final relationship for yarn torque becomes:

$$M=\frac{M_o d}{2D}$$

If the constants of the reference wire are known, M can be calculated from the equation

$$M_o=\frac{n\pi r^4}{2\ell}$$

where n=average value of shear modulus (12×10^6 lbs/in^2) of the reference wire

r=mean radius of the reference wire (.0025 inches)

ℓ=length of the wire (3.50 inches)

accordingly,

$M_o=2.10 \times 10^{-4}$ in.-lbs.

In most of the experiments, M_0 was of the order of ten (10) times the magnitude of the greatest value of yarn torque obtained. This condition must be maintained in order to ensure that the angular deflection of the wire can be neglected relative to the twist in the yarn; this requires a large value of M_0 and therefore a short length of torsion wire. However, it should be noted that the sensitivity of this apparatus increases for longer lengths of wire.

II.3. Expermental Procedures

After indentification coding for fiber content, rotor speed, and combing roller speed, all yarns were conditioned for a minimum of three days in a controlled atmosphere of 68°F±2°F, 65%R.H.±1%R.H. in accordance with ASTM testing standards for textile materials. Yarns were then tested for yarn number using option one of ASTM test method D1907. ASTM test method D1422 was followed in twist determinations. This test, known as the twist-untwist method, is based on the medium of twist contraction; sufficient reverse twist is inserted to restore original length and tension and it is assumed that one half the algebraic difference of twist is the amount originally used in the samples. There is a chance of fiber slippage across the yarn cross section during OES yarn spinning. This slippage causes a differential twist gradient to occur and is likely to cause machine twist (calculated from the relevant twist gear and machine constant) to be greater than the actual mean yarn twist.

There is also the probability that the reversed twist contraction rate differs from the twist extension rate. Studies by Lord and Grady have shown that this method, when compared to the Rockbank surface twist test and the torsional equilibrium test, most accurately approximates the actual twist level for open end spun yarns.[5] It is important that the most accurate method of determining twist be used, for twist is frequently used implicitly "to describe yarn attributes which are not always recognized for what they are. A given level of twist implies certain levels of hairiness, covering power (diameter), hand, twist liveliness (torque), bending stiffness (torsional rididity), etc."[5]

The twist multiples were calculated by,

$$TM=\frac{tpi}{\sqrt{n}}$$.

where TM=twist multiple

tpi=twist per inch

n=yarn number in cotton count

After the yarns were characterized for yarn number, twist, and twist multiple, ten specimens were selected from each sample yarn: five for the torque-tension test and five for the torque uptwist test. Test specimens were prepared in the following manner. A seven inch segment of yarn was mounted on a cardboard specimen holder similar to the one illustrated in Figure 4. The lower end of this

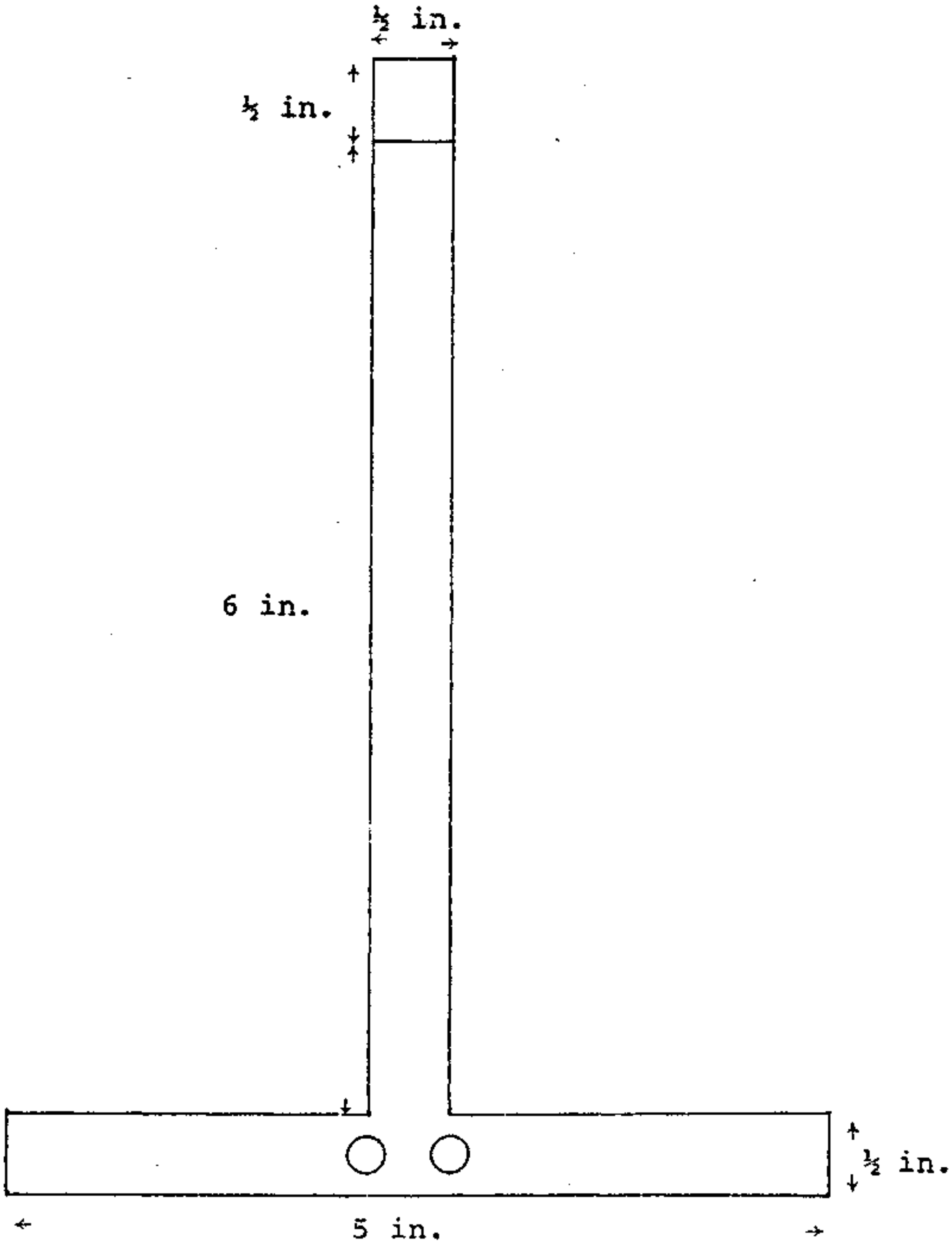


Figure 4. Specimen Holder

specimen holder provides a backstop to the yarn so that it will not untwist when the specimen holder is severed, for this backstop is constrained by the yoke which is part of the torsion wire balance device shown in Figure 5. The specimen holders are constructed so that prescribed weights could be applied to the yarn specimen to determine the effect of yarn tension on yarn torque. The yoke is designed to allow insertion of both incremental uptwist and down-twist to the yarn specimen so that we may observe the effect of that incremental yarn torsion on the threadline torque.

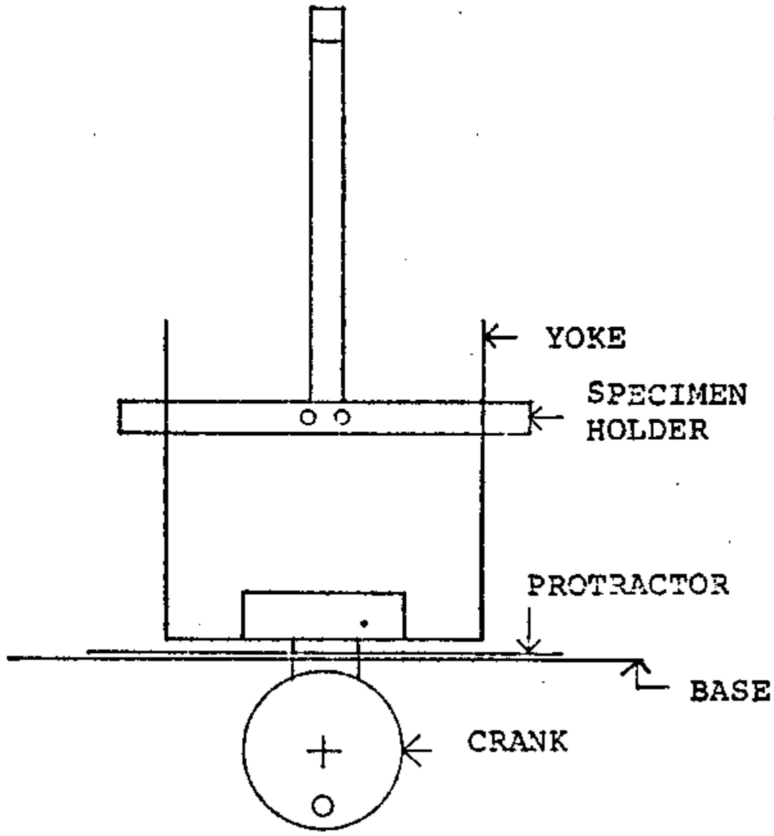


Figure 5. Yoke of Torsion Wire Balance

CHAPTER III

RESULTS AND DISCUSSION

III.1.a. Torque-Tension Results - Laboratory Yarns

The torque response of an open end spun yarn to tension can be used to obtain an indication of the twist liveliness or residual torque remaining in a yarn when the yarn tension is relieved. Figure 6 illustrates how the residual torque is determined for a typical OES yarn. Varying degrees of tension are applied to the yarn and the corresponding yarn torque is determined. After a sequence of tensions are applied, the experimental data is extrapolated to zero tension and residual torque is determined. This residual torque is shown as A in Figure 6. As one might expect the greater the value of A, the more twist lively the yarn is.

For 100% cotton yarns, the residual torque, as a function of combing roller speed at constant nominal counts and twist multiples, is given in Figure 7. An examination of this data reveals that there is no significant trend. Even the yarn with the highest twist multiple and the lowest count does not always have the highest residual torque all of the time; usually one might suggest that the higher the twist multiple, the greater the risidual torque.

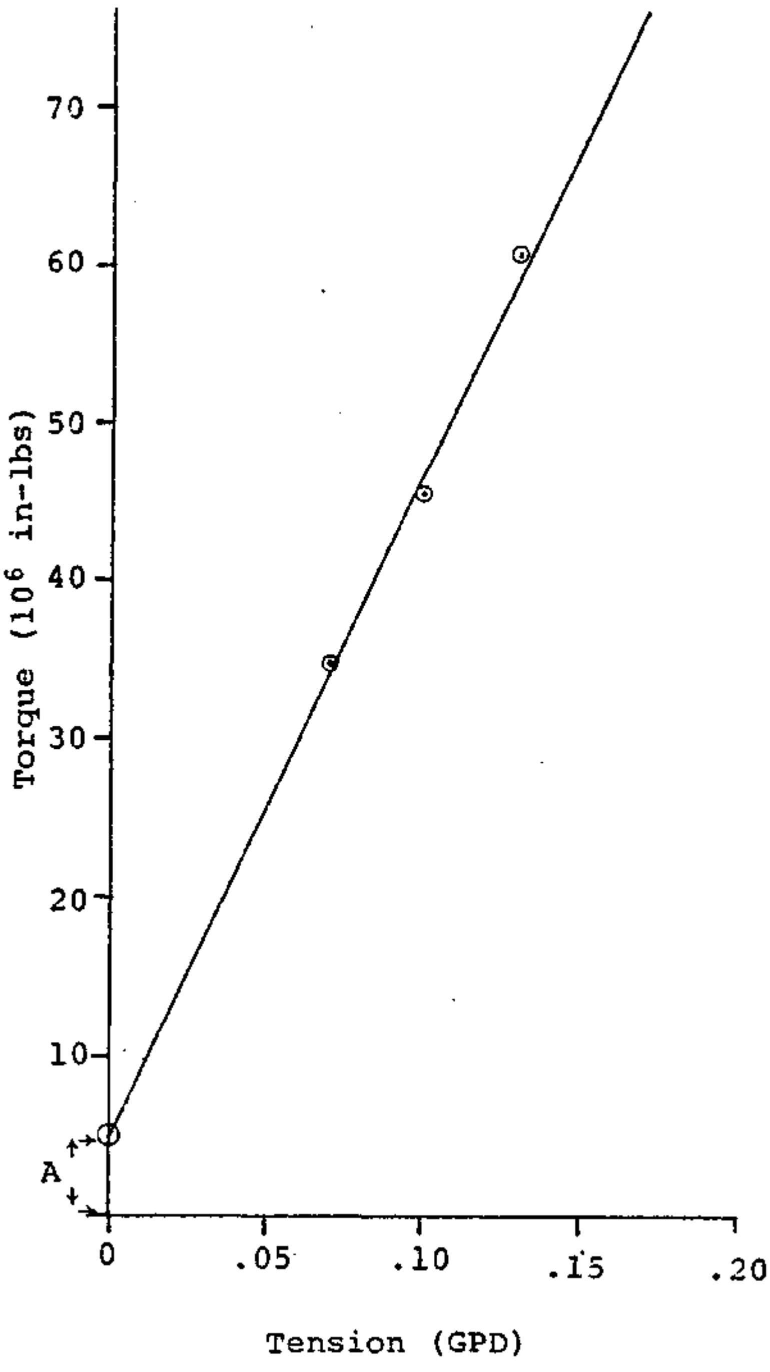


Figure 6. Torque V.S. Tension - Sample Yarn

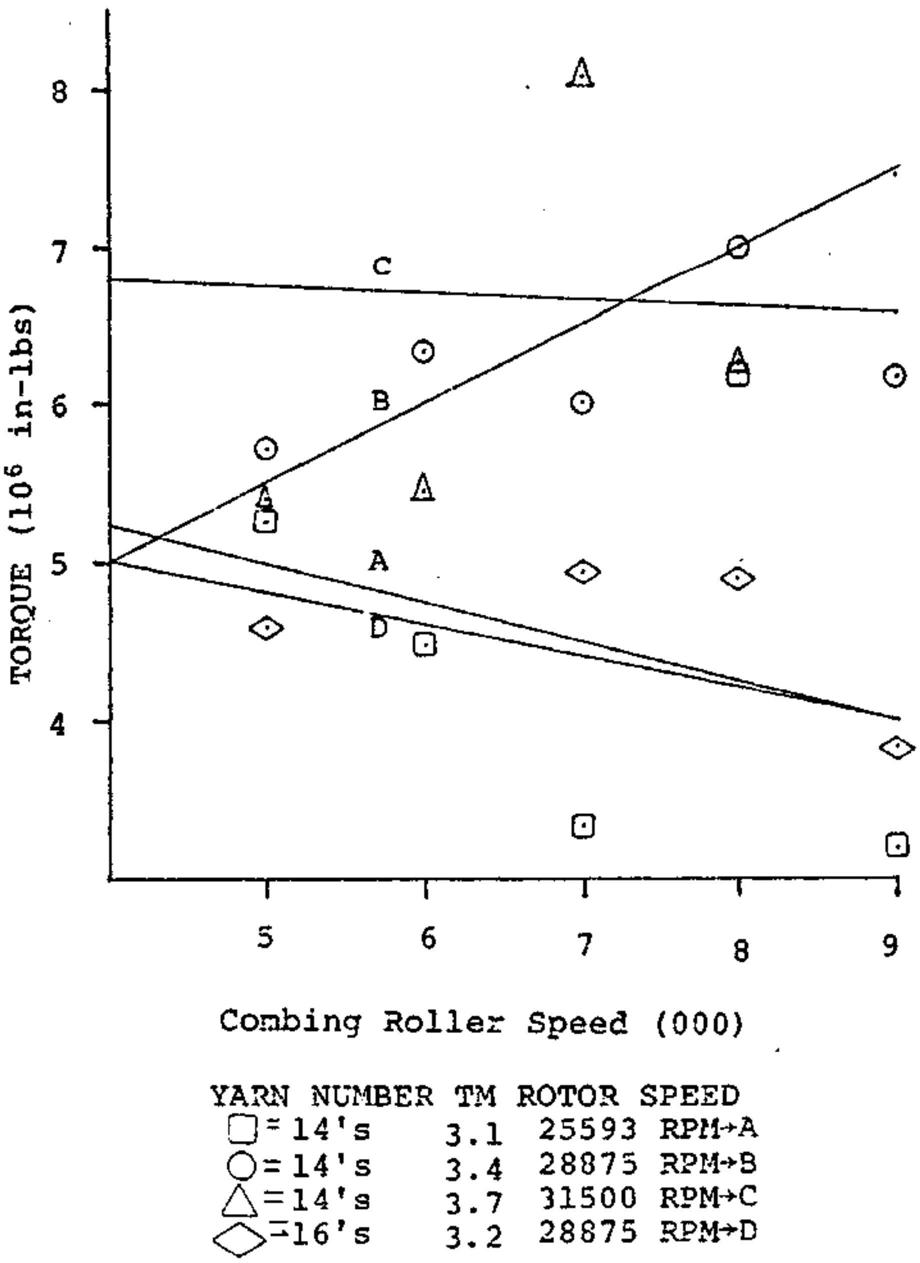


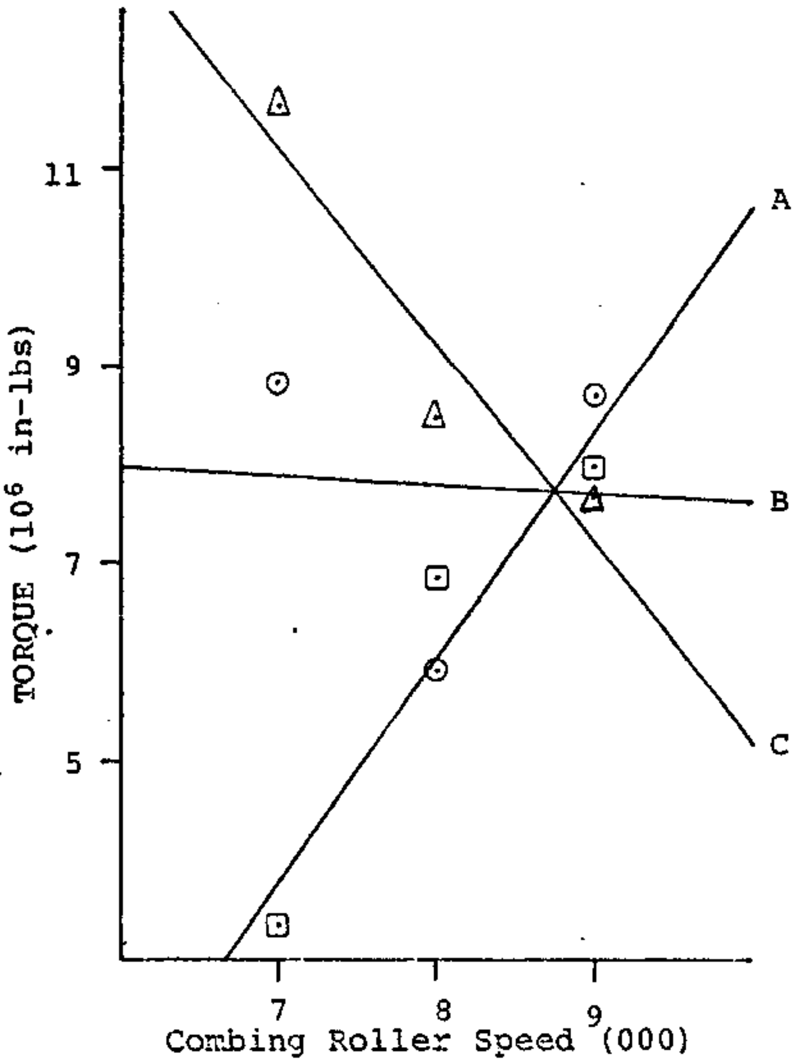
Figure 7. Combing Roller Speed V.S. Residual Torque:
100% Cotton Yarn

In Figure 8, we illustrate the residual torques as a function of combing roller speeds for different twist multiples for cotton-polyester yarns. Again, no clear trend is apparent. Accordingly, from the data presented in Figures 7 and 8, one can conclude that combing roller speed has no appreciable effect on residual torque.

In Figure 9 we illustrate the residual torque as a function of twist multiplier at constant combing roller speed for 100% cotton yarns. It can be concluded from this data that residual torque is directly proportional to twist multiplier.

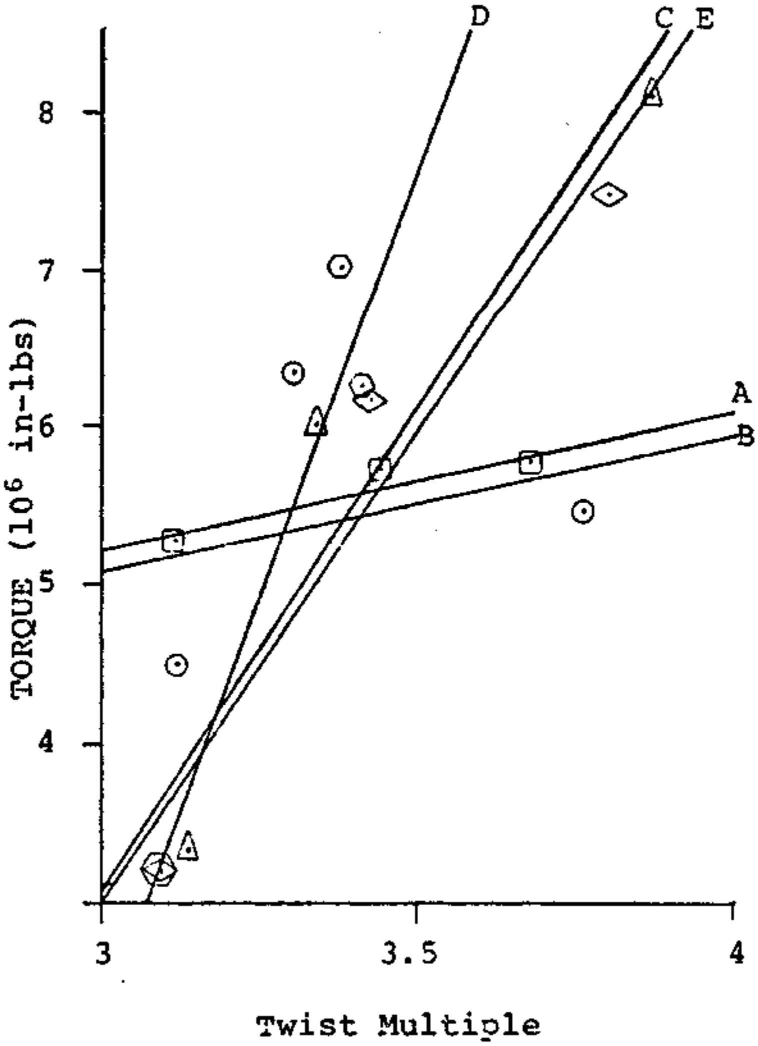
However in Figure 10, we do not observe this clear correlation for the cotton-polyester yarns. This might be explained by the expected nonuniform distribution of cotton and polyester throughout the yarn cross-section.

In Appendix A, the average data for the five tests for each sample yarn is presented for the torque-tension tests.



YARN NUMBER	TM	ROTOR SPEED
□ = 14's	3.78	28970 RPM→A
○ = 14's	3.74	31500 RPM→B
△ = 14's	3.84	32913 RRM→C

Figure 8. Combing Roller Speed V.S. Residual Torque: Cotton/Polyester Yarn



Combing Roller Speed

□ = 5000 RPM→A
○ = 6000 RPM→B
△ = 7000 RPM→C
⬡ = 8000 RPM→D
◇ = 9000 RPM→E

Figure 9. TM V.S. Residual Torque: 100% Cotton Yarn

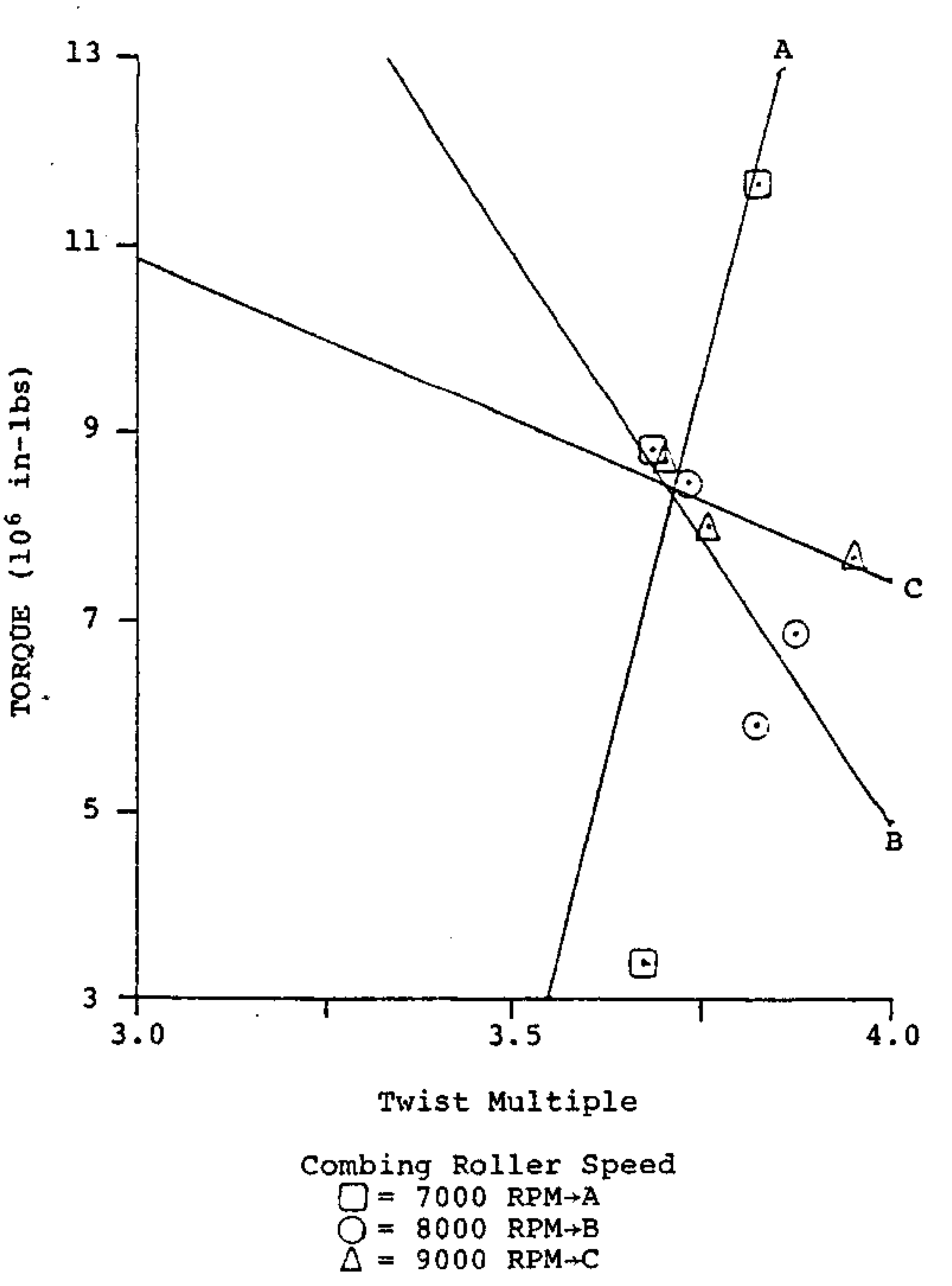


Figure 10. TM V.S. Residual Torque:
Cotton/Polyester Yarn

III.1.b. Torque-Tension Results : Commercial Yarns

A series of experiments were carried out on similar OES and ring spun yarns supplied by the Coats and Clark company. The characteristics of these yarns are listed in Table 2.

Table 2. Commercial Yarn Characteristics

	OES	RING SPUN
yarn number	9.69cc (549 D)	9.63cc (552 D)
T.P.I.	12.0	11.1
T.M.	3.85	3.57

The above characteristics suggest that both yarns are simila and can be compared with regard to their torque-tension behavior. In III.2.b, we compare their torque-twist behavio Figure 11 illustrates the comparative torque-tension data for both yarns. The residual torque for the OES yarn is 11.9 $\times 10^{-6}$ in-lbs while the residual torque for the ring spun yarns is 9.1 $\times 10^{-6}$ in-lbs. Therefore, eventhough the OES yarn has only 8% more twist than the corresponding ring spun yarn, the OES yarn has a residual torque which is 31% greater than the ring spun yarn. This data suggests that the twist liveliness for OES yarns is greater than

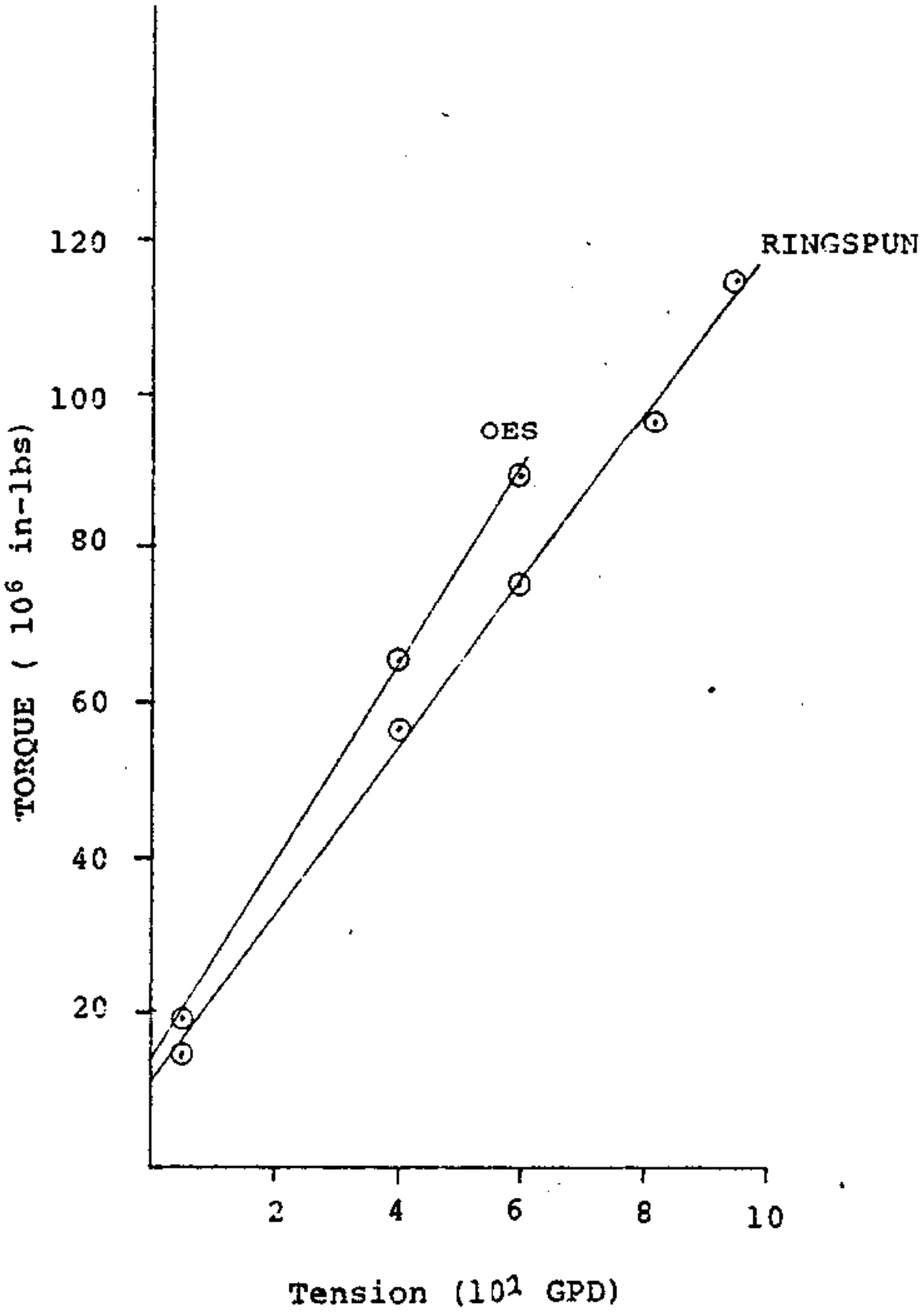


Figure 11. Torque V.S. Tension - Commercial Yarns

that for ring spun yarns. This increased twist liveliness might be a result of the relatively high contribution to threadline torque by the wrapper fiber bending moment. The slopes for both yarns appear to be almost parallel as might be expected. The data is given in Table 3.

III.2.a. Torque-Twist Results - Laboratory Yarns

The torque response of an open end spun yarn to incremental uptwisting or downtwisting can be used to determine the effect of torque transients on the structure of open end spun yarns. For example, during processing there exists a threadline torque at the yarn formation point. This torque is most probably a function of rotor speed, combing roller speed, yarn tension, fiber to metal friction, and fiber properties. If one were to keep all of these parameters constant except for rotor speed, it would be expected that threadline formational torque would be proportional to the rate of twist insertion or rotor speed. However, if a periodic twist slippage occurs, one would expect a momentary drop in threadline torque and a resulting decrease in threadline twist.

Work done by Brookstein and Backer indicates that for the texturing threadline, a momentary twist slippage results in a concentration of twist decrease over a small portion of yarn, while the remainder of the yarn is relatively unaffected.[14] This is a consequence of the fact that the formation rigidity of the texturing threadline is several

TABLE 3. TORQUE TENSION RESULTS: COMMERCIAL YARNS

YARN DESCRIPTION	GPD	TORQUE(in-lbs x10^6)
commercial ring spun		
yarn type - 100% cotton	.005	13.4
cotton count - 9.63 (552 D)	.041	56.6
ring spun s twist	.058	74.9
T.P.I. 11.07	.078	96.3
T.M. 3.58	.095	114.6

LINEAR REGRESSION

TORQUE(10^6in-lbs)=1121(GPD)+9.05

YARN DESCRIPTION	GPD	TORQUE(in-lbs x10^6)
commercial OES		
yarn type - 100% cotton	.005	18.9
cotton count 9.69 (549 D)	.042	65.5
O.E.S. z twist	.059	89.9
T.P.I. 11.97		
T.M. 3.85		

LINEAR REGRESSION

TORQUE(10^6in-lbs)=1307(GPD)+11.92

orders of magnitude less than the incremental torque-twist rigidity. In Figure 12, we illustrate the situation present during steady state where we operate at torque level A with a corresponding twist level A. Suddenly, a disturbance results in a torque drop to level B in the system. The yarn twist at the formation point drops to level B while the already formed yarn drops to just B´. Accordingly, there is a large local disparity in twist and this results in a negative effect on the quality of the yarn.

In this study, an attempt was made to characterize formation torsional rigidity and incremental regidity for OES yarns to determine if behavior similar to the texturing threadlines exists.

In Figure 13, we present a typical graph of torque versus twist for OES yarns. The initial slope of A to B corresponds to the incremental torsional rigidity of the yarns. Refering to Figure 13, the yarn was first uptwisted from A to B, then downtwisted from B to C to D, and then uptwisted back to E.

For 100% cotton yarns, the torsional rigidity, as a function of combing roller speed, at a constant nominal counts and twist multiples, is given in Figure 14.

This data reveals that above a 7200 RPM combing roller speed, the incremental torsional rigidity of OES yarns increased with twist. Nevertheless, for the two lower twist levels (14's), one can conclude that incremental

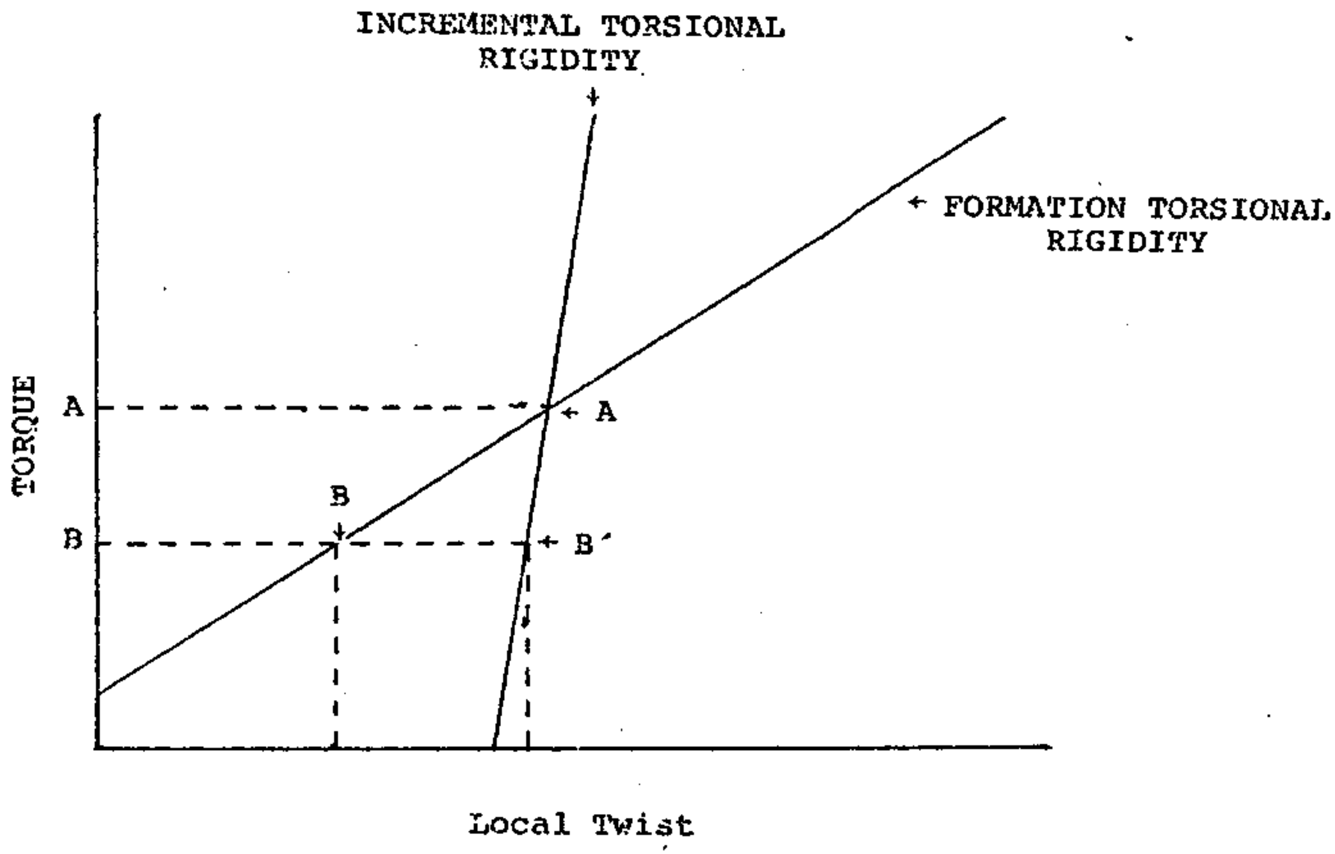
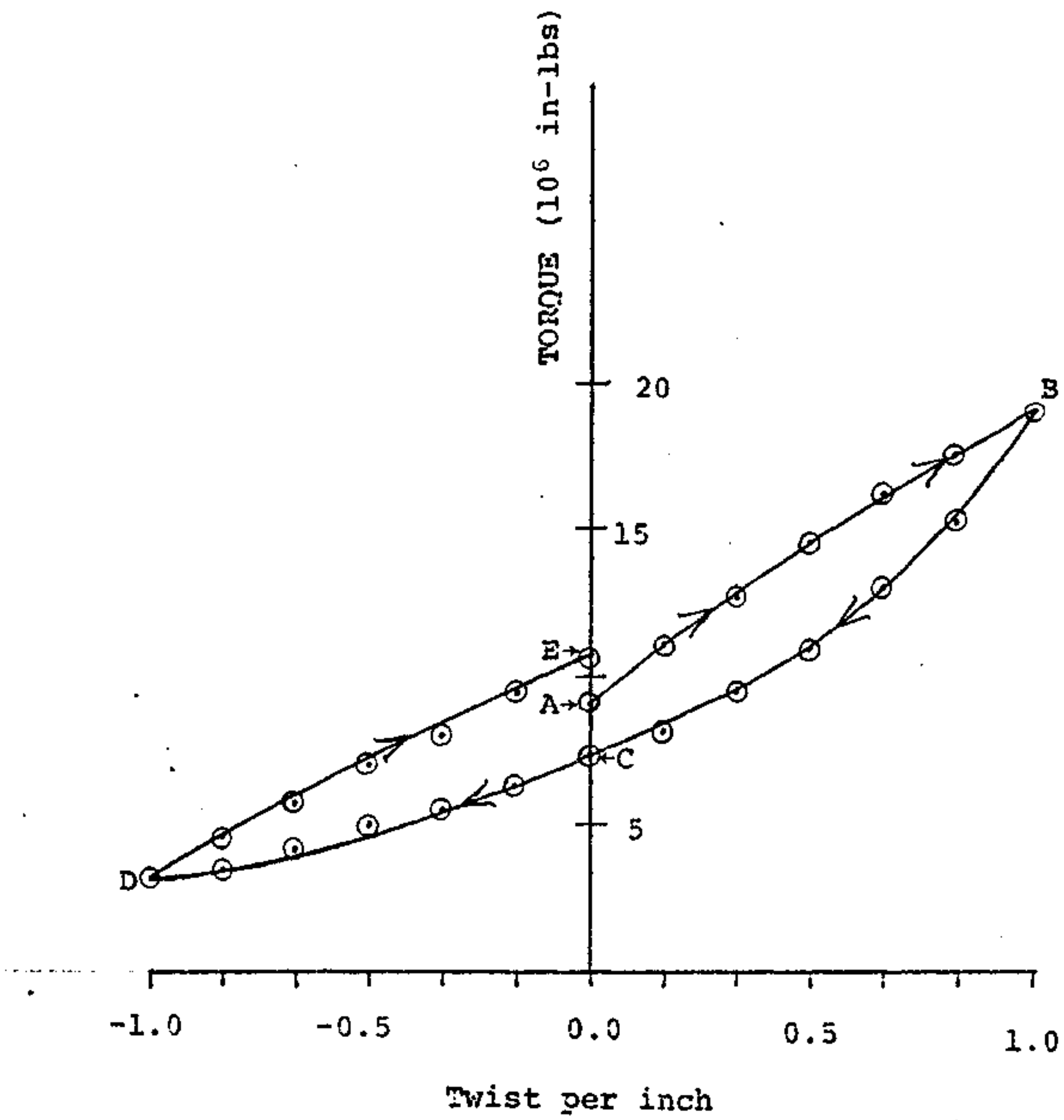


Figure 12. Comparison of Formational Torsional Rigidity to Incremental Torsional Rigidity: Model



rotor speed	28875 RPM
combing roller speed RPM	7000 RPM
yarn number	16's
fiber content	100% cotton
TPI	12.7
TM	3.13

Figure 13. Torque V.S. Twist for a Typical OES Yarn

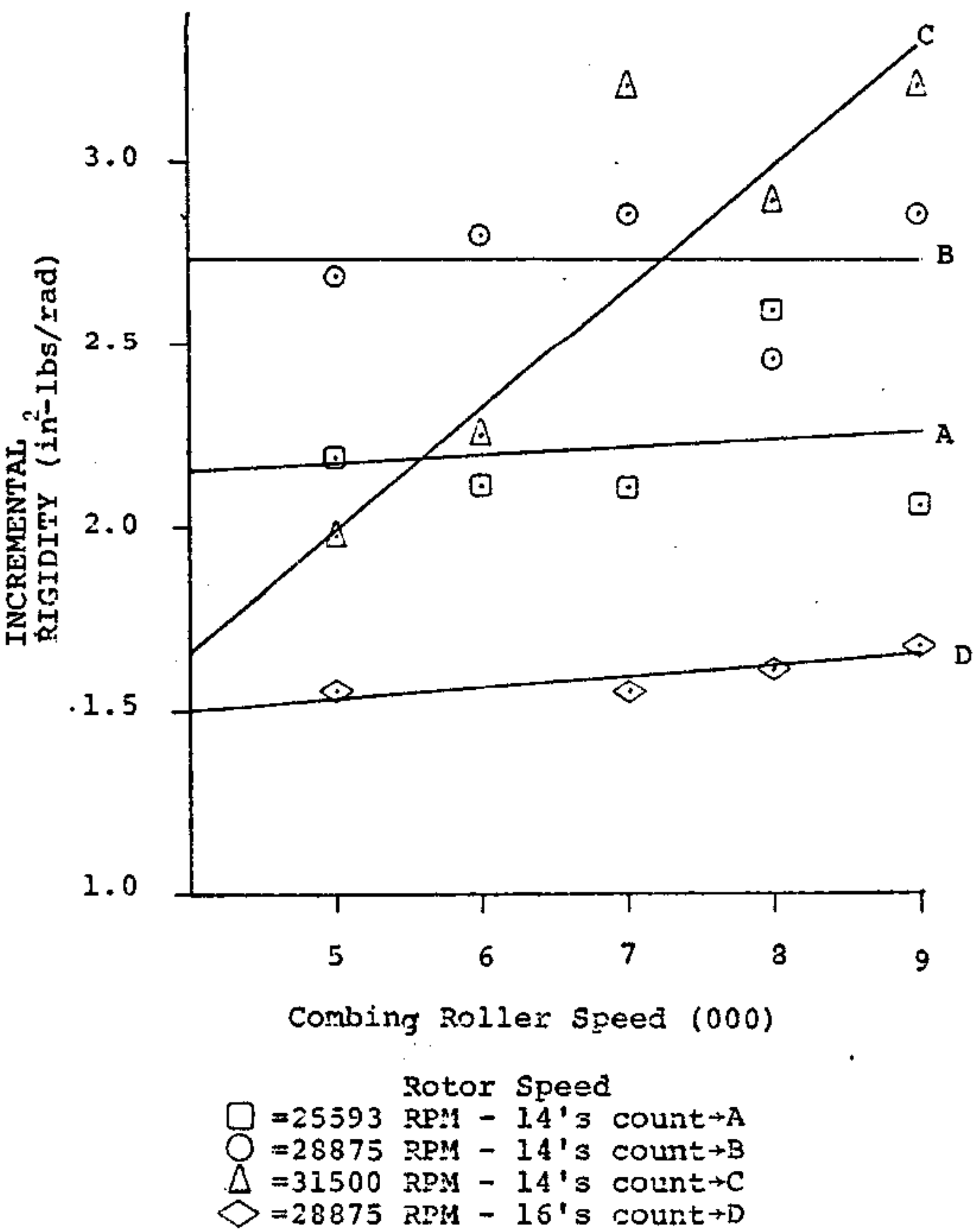


Figure 14. Combing Roller Speed V.S. Rigidity: 100% Cotton Yarn

torque is independent of combing roller speed. Also it is evident that the finer yarn (16's) has a lower rigidity than the corser one (14's).

The cotton/polyester torsional rigidity data for various combing roller speeds is presented in Figure 15. Here, the data seems scattered and one finds it difficult to make any judgement as to the effect of combing roller speeds on incremental rigidity. Other than to judge this scattering of data on the basis of nonuniform fiber separation and yarn formation during open end spinning of cotton/polyester yarns, one has no explanation of this behavior to offer at this time.

The incremental torsional rigidity for 100% cotton OES yarns at constant combing roller speeds and varying twist multiples is presented in Figure 16. For every combing roller speed other than 6000 RPM, one observes that rigidity increases with twist as might be expected.

For the cotton/polyester yarns, one again observes in Figure 17, the scattering of torsional behavior data similar to that found in Figures 8, 10 and 15. The nonuniformity of fiber separation and yarn formation is again the suggested cause of this data scattering.

The incremental torsional rigidity of OES cotton yarns is compared to the formation rigidity in Figure 18. From this figure, we see that the ratio of incremental rigidity to formational rigidity increases with twist.

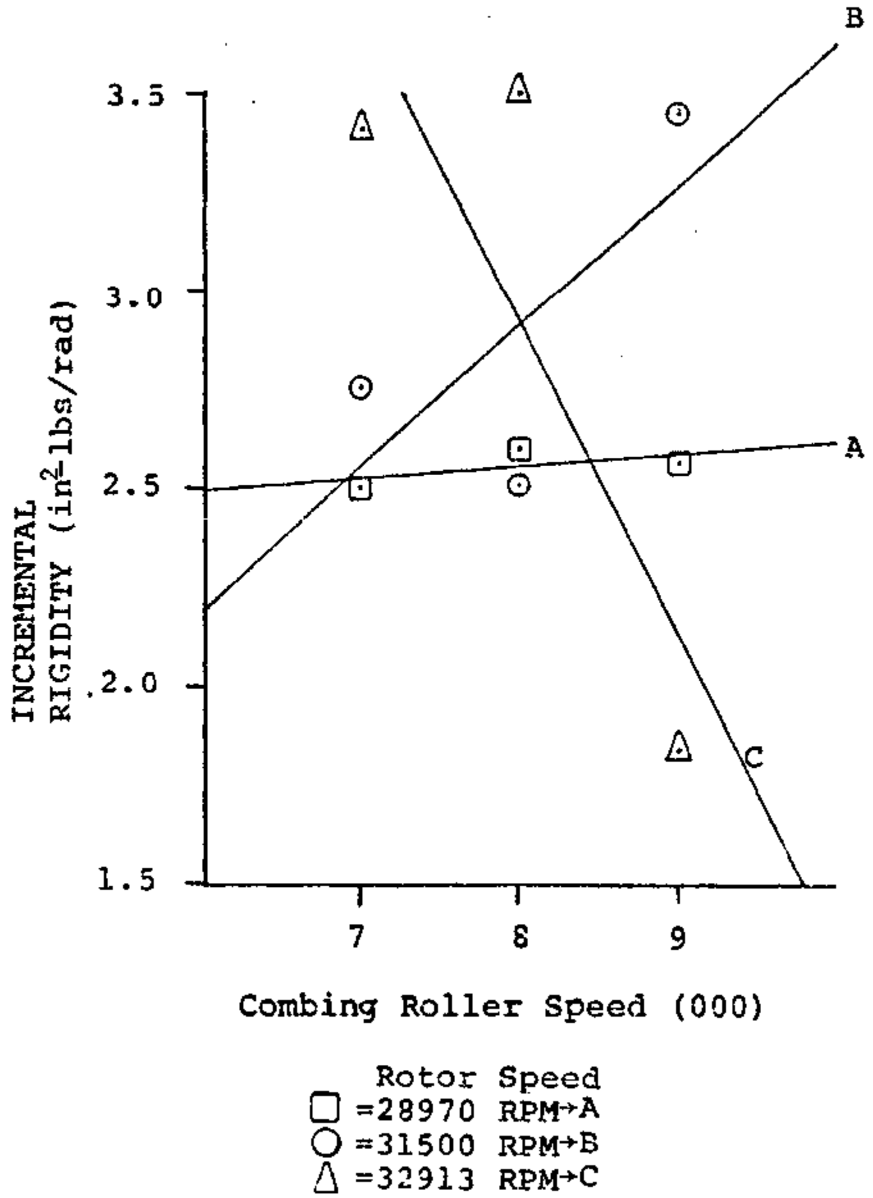


Figure 15. Combing Roller Speed V.S. Rigidity: Cotton/Polyester Yarn

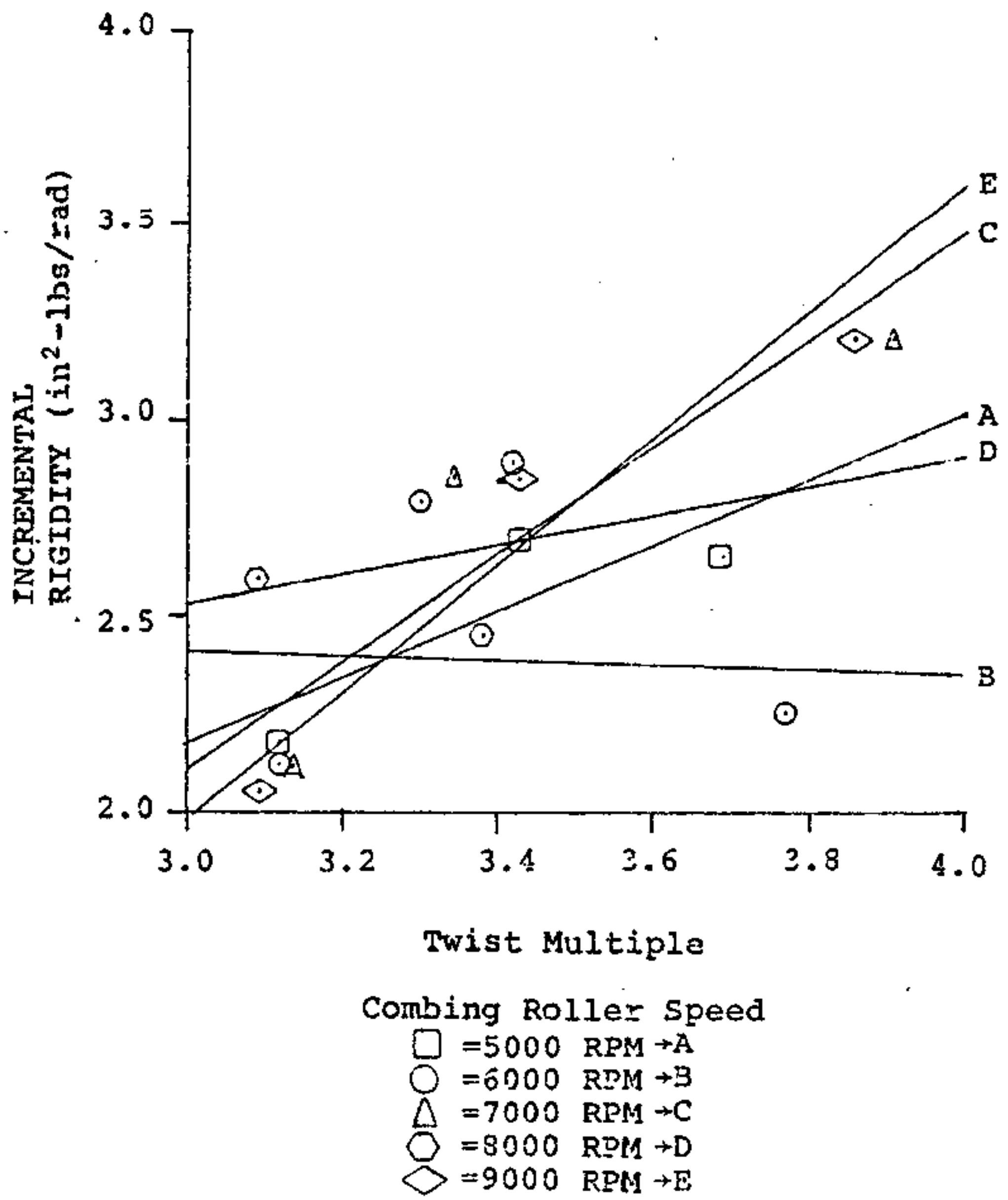


Figure 16. T.M. V.S. Rigidity: 100% Cotton Yarn

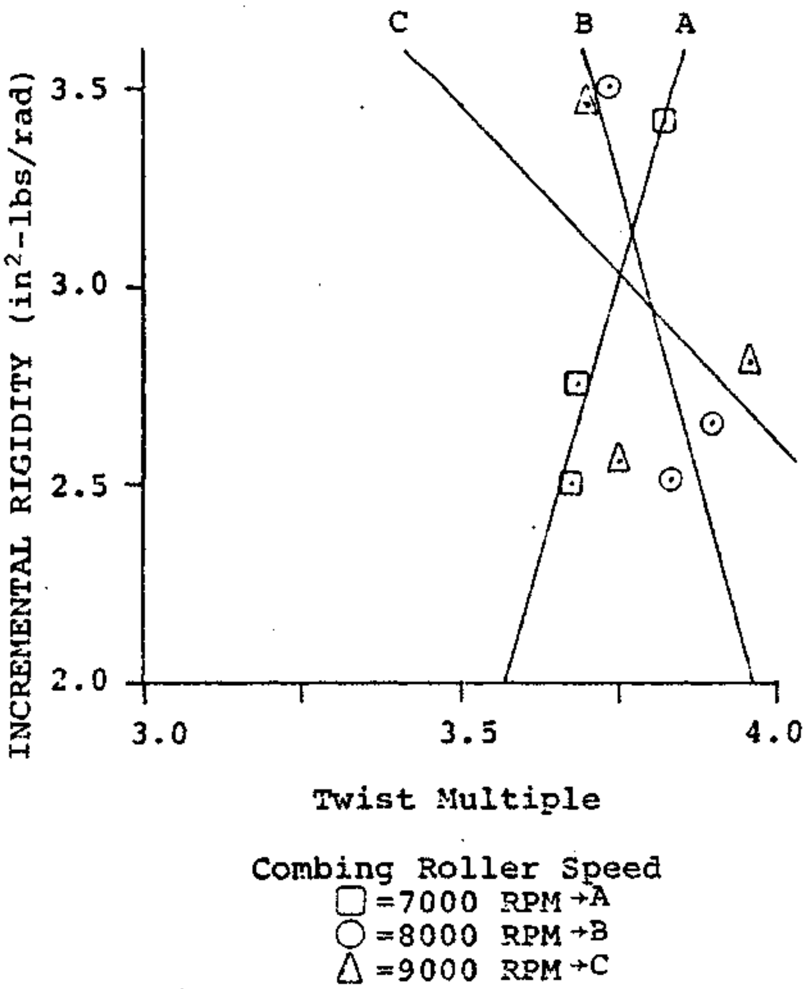


Figure 17. T.M. V.S. Rigidity:
Cotton/Polyester Yarns

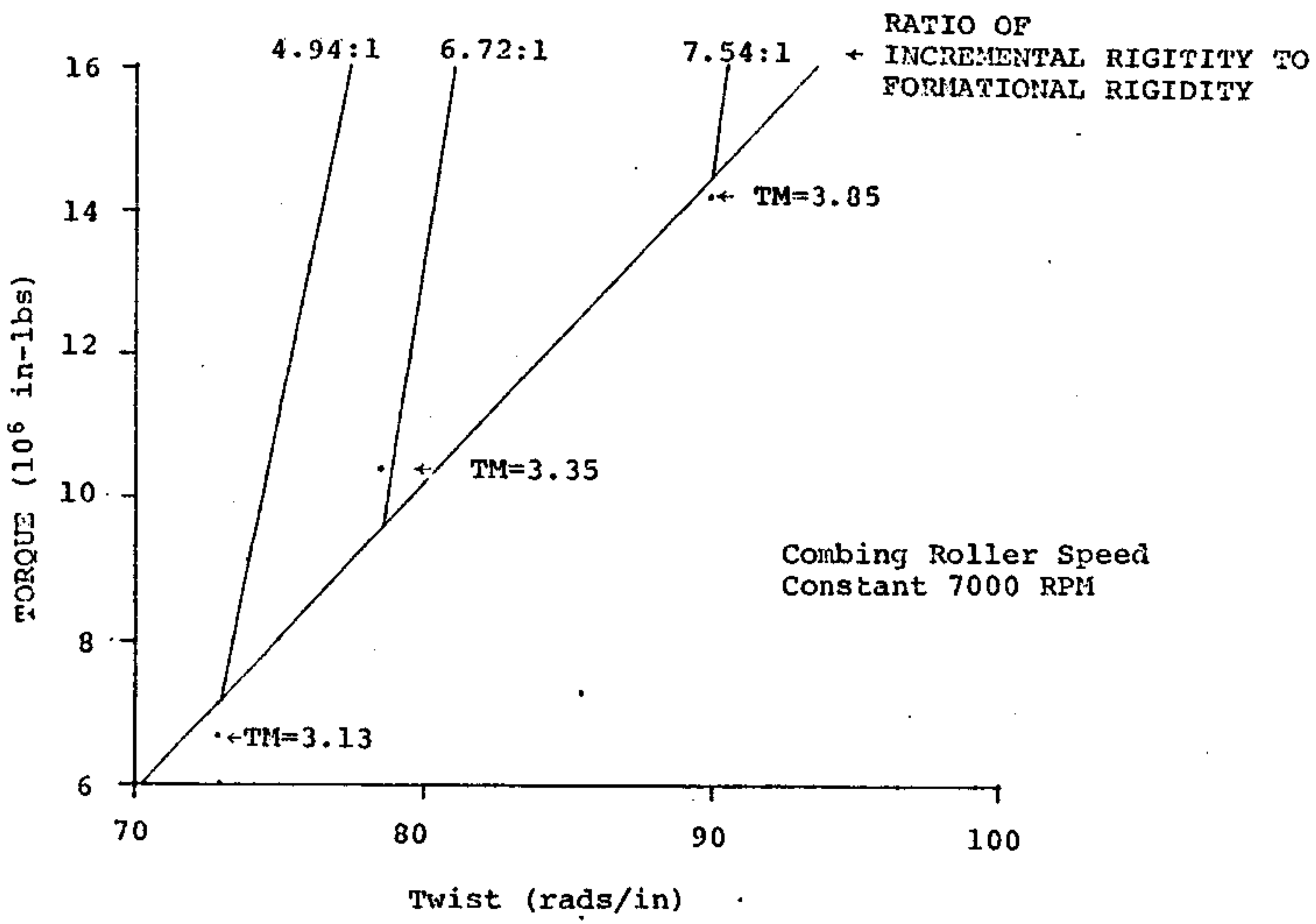


Figure 18. Comparison of Formational Torsional Rigidity to Incremental Torsional Rigidity: 100% Cotton Yarn

Consequently, one can expect that for higher twist, there is a greater chance for twist nonuniformity after a periodic twist slippage at the rotor for reasons explained earlier. The corresponding data for cotton/polyester yarns is presented in Figure 19. Again, one observes that the ratio of rigidities increases with twist, but in this case, the ratios are not as large as those for the corresponding 100% cotton yarns.

In appendix B, the average torque uptwist-downtwist-uptwist data for all of the studied yarns is presented.

III.2.b. Torque-Twist Results-Commercial Yarns

The Torque-Uptwist-Downtwist-Uptwist data for both the commercial OES and ring spun yarns, mentioned in III.1.b, is presented in Figure 20. Aside from the slight difference in magnitude of torque, the general slopes of both sets of data are similar to each other. The OES yarns appear to have a greater hysteresis loss than the ring spun does. This is probably due to the greater fiber slippage during incremental twisting. Again this is a consequence of reduced fiber migration for OES yarns.

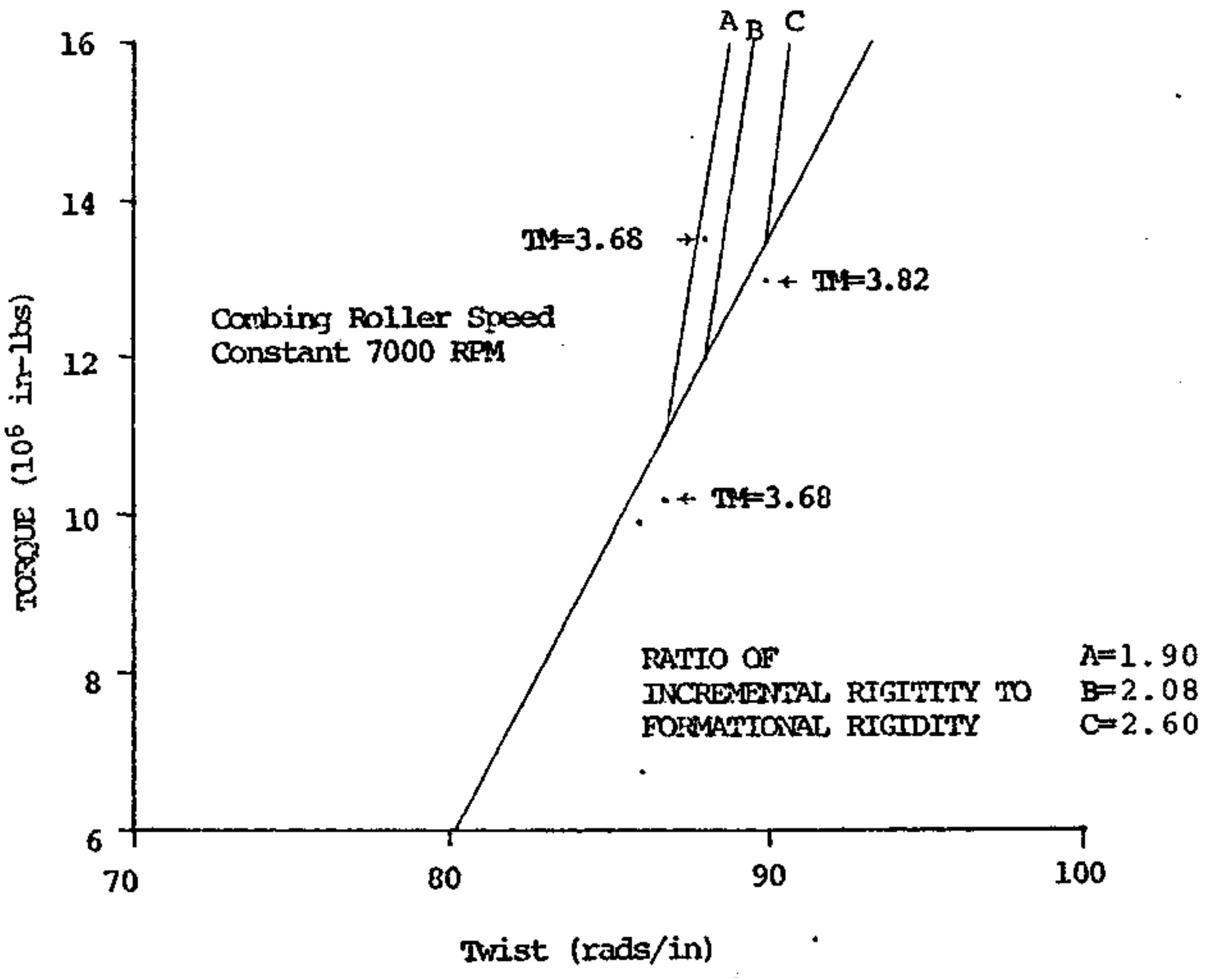


Figure 19. Comparison of Formational Torsional Rigidity to Incremental Torsional Rigidity: Cotton/Polyester Yarn

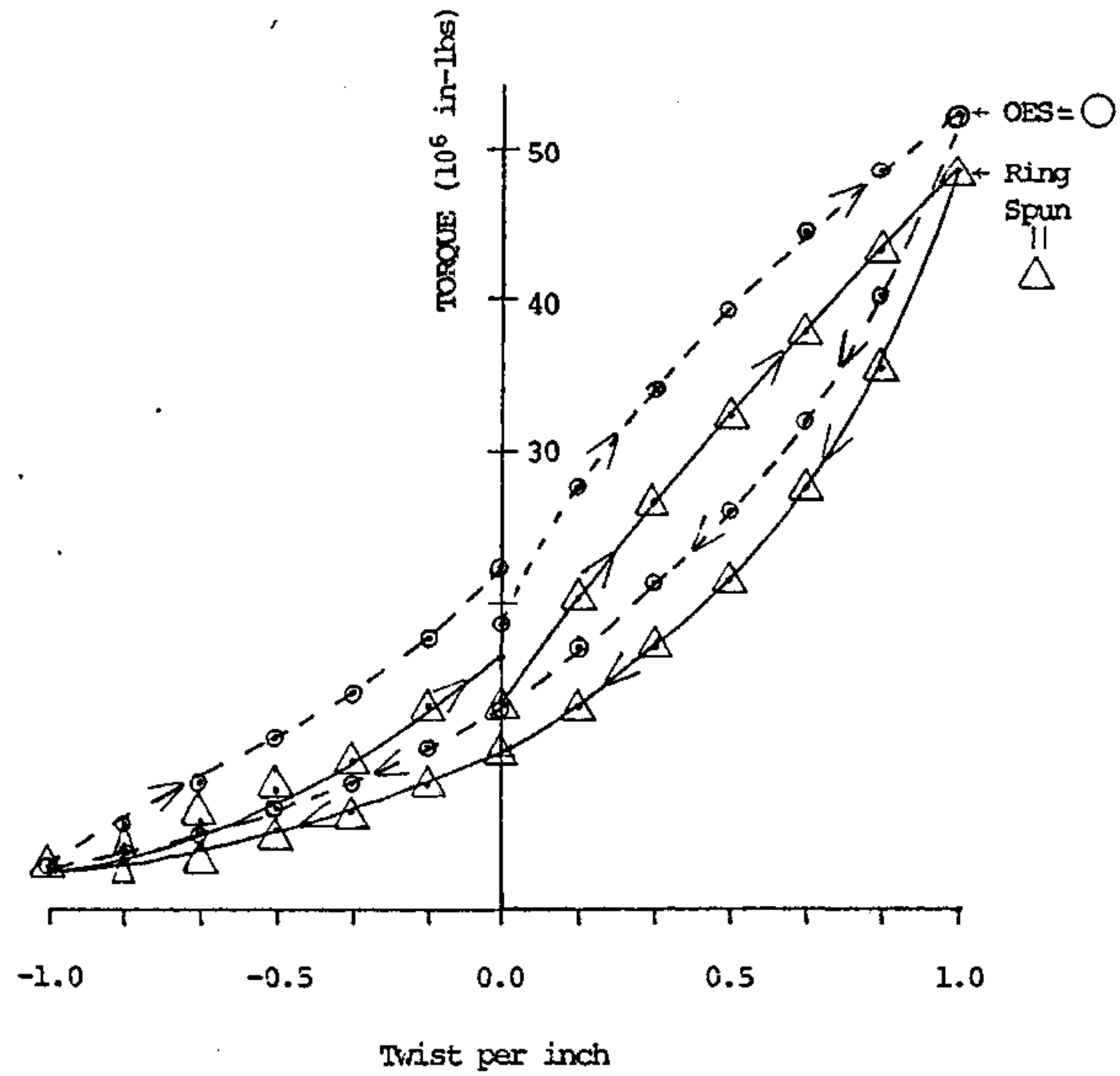


Figure 20. Torque Uptwist - Downtwist - Uptwist Plot: Commercial Yarns

CHAPTER IV

CONCLUSIONS

The residual torque which is the threadline torque extrapolated to zero yarn tension does not appear to be a function of combing roller speed for either 100% cotton or cotton/polyester yarns. Accordingly, if one is concerned with residual torque which leads to twist liveliness, it is not necessary to be concerned with combing roller speed. In view of the fact that combing roller speed affects energy consumption, this is a significant finding.[12] The residual torque increases with twist multiplier for cotton yarns, as might be expected. The data is not conclusive though for cotton/polyester blends.

After comparing the torque-tension response for similar OES 100% cotton yarns and ring spun 100% cotton yarns, it was found that OES yarns are slightly more torque responsive to changes in threadline tension.

The incremental torsional rigidity of OES 100% cotton yarns increases with combing roller speed above 7200 RPM. Since the incremental rigidity of OES yarns helps to determine twist uniformity along the threadline, this finding is significant. For cotton/polyester yarns, there is no clear trend as to the effect of combing roller speed on incremental torsional rigidity.

The incremental torsional rigidity of 100% cotton OES yarns clearly rises with twist multiplier, as might be expected. However, the cotton/polyester data is again scattered with no apparent trend.

A comparison of the incremental torsional rigidity and the formational torsional rigidity for OES yarns indicates that there is an order of magnitude difference between the two. Hence, as explained earlier, a transient torque disturbance will manifest a concentrated region of reduced twist at the yarn formation point. This reduced twist length of yarn will remain in the yarn and appear as a nonuniformity.

CHAPTER V

RECOMMENDATIONS FOR FUTURE WORK

This study has shown that 100% cotton yarns behave differently from blends of cotton/polyester yarns. Thus, it is recommended that further study be carried out to find the cause of this difference in torsional behavior.

The rotor speed should be suddenly reduced to determine if in fact the local twist does change and remain concentrated at the yarn formation point as is predicted.

It is also suggested that this work be followed by a theoretical study of the origin of torque in the OES threadline.

APPENDIX A

Torque-Tension Results:
Laboratory Yarns

Identification Code Number	Rotor Speed RPM	Combing Roller Speed RPM	Yarn Number Cotton Count	Yarn Number Denier	T.P.I.	T.M.	Fiber Type
1	25593	5000	14.3	373	11.7	3.11	cotton
2	25593	6000	14.0	380	11.6	3.11	cotton
3	25593	7000	13.8	385	11.6	3.13	cotton
4	25593	8000	14.0	380	11.6	3.09	cotton
5	25593	9000	14.3	371	11.7	3.09	cotton
6	28875	5000	16.4	324	13.2	3.24	cotton
7	28875	6000	13.8	397	12.2	3.30	cotton
8	28875	7000	16.5	322	12.7	3.13	cotton
9	28875	8000	16.1	330	13.0	3.25	cotton
10	28875	9000	16.5	323	13.3	3.27	cotton
11	31500	5000	16.3	327	13.9	3.44	cotton
12	31500	6000	13.9	384	14.0	3.77	cotton
13	31500	7000	13.8	387	14.3	3.87	cotton
14	31500	8000	13.7	389	12.6	3.42	cotton
15	31500	9000	13.7	387	14.1	3.81	cotton
16	28875	5000	13.5	393	12.6	3.44	cotton
17	28875	7000	14.0	380	12.5	3.35	cotton
18	28875	8000	14.3	371	12.8	3.38	cotton
19	28875	9000	13.8	385	12.7	3.43	cotton
20	31500	5000	14.5	366	14.0	3.68	cotton
21	28970	7000	14.1	377	13.8	3.68	35% cot/65% poly
22	28970	8000	14.0	379	14.6	3.89	35% cot/65% poly
23	28970	9000	14.3	373	14.2	3.76	35% cot/65% poly
24	31500	7000	16.6	321	14.3	3.51	35% cot/65% poly
25	31500	7000	14.4	368	14.0	3.68	35% cot/65% poly
26	31500	8000	14.0	380	14.3	3.83	35% cot/65% poly
27	31500	9000	16.7	319	14.3	3.51	35% cot/65% poly
28	31500	9000	14.0	381	13.8	3.70	35% cot/65% poly
29	32913	8000	16.1	331	14.1	3.51	35% cot/65% poly
30	32913	8000	14.1	378	14.0	3.74	35% cot/65% poly
31	32913	9000	16.2	329	14.5	3.62	35% cot/65% poly
32	32913	9000	14.5	366	15.1	3.96	35% cot/65% poly
33	32913	7000	14.1	378	14.3	3.82	35% cot/65% poly
34	commercial ring spun		9.6	552	11.1	3.57	cotton
35	commercial open end spun		9.7	547	12.0	3.85	cotton

Sample Yarn No. 1.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	9.4		
+ .167	12.3		
+ .333	14.2	M=13.7 in^{2}lbs/turn	M=2.18 in^{2}lbs/rad
+ .500	16.7		K= 9.73 in'lbs
+ .667	19.2		
+ .833	21.1		
+ 1.000	23.3		
+ .833	17.2		
+ .667	12.8		
+ .500	12.5	M=14.7 in^{2}lbs/turn	M=2.33 in^{2}lbs/rad
+ .333	10.4		K=5.99 in'lbs
+ .167	8.6		
0	7.3		
- .167	6.2		
- .333	5.1	M=4.79 in^{2}lbs/turn	M=0.76 in^{2}lbs/rad
- .500	4.4		K=7.02 in'lbs
- .667	3.9		
- .833	3.2		
- 1.000	2.3		
- .833	4.4		
- .667	6.2		
- .500	7.6	M=8.81 in^{2}lbs/turn	M=1.4 in^{2}lbs/rad
- .333	8.7		K=11.6 in'lbs
- .167	9.9		
0	11.5		

Sample Yarn No. 2.

UPTWIST(TPI)		TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
	0	8.2		
+	.167	11.3		
+	.333	15.2	M=13.3 in^{2}lbs/turn	M=2.12 in^{2}lbs/rad
+	.500	17.1		K=10.0 in'lbs
+	.667	19.0		
+	.833	20.8		
+	1.000	22.9		
+	.833	17.5		
+	.667	14.2		
+	.500	11.3	M=15.2 in^{2}lbs/turn	M=2.42 in^{2}lbs/rad
+	.333	9.9		K=5.38 in'lbs
+	.167	8.2		
	0	6.9		
-	.167	6.0		
-	.333	4.9	M=5.06 in^{2}lbs/turn	M=0.805 in^{2}lbs/rad
-	.500	4.0		K=6.73 in'lbs
-	.667	3.1		
-	.833	2.5		
-	1.000	1.9		
-	.833	3.5		
-	.667	5.3		
-	.500	6.9	M=10.7 in^{2}lbs/turn	M=1.69 in^{2}lbs/rad
-	.333	8.6		K=12.4 in'lbs
-	.167	10.7		
	0	12.6		

Sample Yarn No. 3.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	6.7		
+ .167	10.4		
+ .333	13.1	M=13.3 in^{2}lbs/turn	M=2.1 in^{2}lbs/rad
+ .500	15.3		K=7.85 in'lbs
+ .667	16.7		
+ .833	18.6		
+ 1.000	20.7		
+ .833	14.7		
+ .677	11.9		
+ .500	9.6	M=13.6 in^{2}lbs/turn	M=2.16 in^{2}lbs/rad
+ .333	8.0		K=4.33 in'lbs
+ .167	7.0		
0	5.9		
- .167	4.6		
- .333	3.9		
- .500	3.2	M=4.21 in^{2}lbs/turn	M=.669 in^{2}lbs/rad
- .667	2.8		K=5.50 in'lbs
- .833	2.1		
- 1.000	1.4		
- .833	3.3		
- .677	4.6		
- .500	6.2	M=8.81 in^{2}lbs/turn	M=1.4 in^{2}lbs/rad
- .333	7.4		K=10.4 in'lbs
- .167	8.9		
0	10.4		

Sample Yarn No. 4.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	10.4		
+ .167	13.7		
+ .333	16.6	M=16.3 in^{2}lbs/turn	M=2.59 in^{2}lbs/rad
+ .500	19.6		K=10.9 in'lbs
+ .667	22.0		
+ .833	24.0		
+ 1.000	27.1		
+ .833	20.4		
+ .667	16.1		
+ .500	13.8	M=18.3 in^{2}lbs/turn	M=2.92 in^{2}lbs/rad
+ .333	10.8		K=5.86 in'lbs
+ .167	8.9		
0	8.0		
- .167	6.9		
- .333	5.5		
- .500	4.8	M=5.15 in^{2}lbs/turn	M=0.819 in^{2}lbs/rad
- .667	4.2		K=7.67 in'lbs
- .833	3.4		
- 1.000	2.8		
- .833	4.8		
- .667	6.1		
- .500	7.1	M=9.25 in^{2}lbs/turn	M=1.47 in^{2}lbs/rad
- .333	8.4		K=12.07 in'lbs
- .167	10.4		
0	12.6		

Sample Yarn No. 5.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	7.2		
+ .167	10.5		
+ .333	12.3	M=12.9 in^{2}lbs/turn	M=2.05 in^{2}lbs/rad
+ .500	14.5		K=7.86 in'lbs
+ .667	16.7		
+ .833	18.6		
+ 1.000	20.3		
+ .833	13.7		
+ .667	11.3		
+ .500	9.6	M=12.6 in^{2}lbs/turn	M=2.00 in^{2}lbs/rad
+ .333	8.9		K=4.70 in'lbs
+ .167	7.2		
0	5.9		
- .167	5.0		
- .333	4.1		
- .500	3.3	M=4.62 in^{2}lbs/turn	M=0.735 in^{2}lbs/rad
- .667	2.3		K=5.73 in'lbs
- .833	1.8		
- 1.000	1.4		
- .833	3.4		
- .667	4.3		
- .500	5.2	M=7.75 in^{2}lbs/turn	M=1.23 in^{2}lbs/rad
- .333	6.8		K=9.40 in'lbs
- .167	8.2		
- 0	9.5		

Sample Yarn No. 6.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	8.6		
+ .167	10.9		
+ .333	12.6	M=9.78 in^2lbs/turn	M=1.55 in^2lbs/rad
+ .500	14.9		K=9.26 in'lbs
+ .667	16.4		
+ .833	17.1		
+ 1.000	18.5		
+ .833	13.9		
+ .667	12.0		
+ .500	9.8	M=11.2 in^2lbs/turn	M=1.79 in^2lbs/rad
+ .333	8.5		K=5.33 in'lbs
+ .167	7.5		
0	6.5		
- .167	5.3		
- .333	4.8		
- .500	3.9	M=3.92 in^2lbs/turn	M=0.623 in^2lbs/rad
- .667	3.4		K=6.13 in'lbs
- .833	2.9		
- 1.000	2.5		
- .833	4.1		
- .667	5.4		
- .500	7.0	M=7.73 in^2lbs/turn	M=1.23 in^2lbs/rad
- .333	7.9		K=10.5 in'lbs
- .167	9.0		
0	10.4		

Sample Yarn No. 7.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	10.9		
+ .167	14.3		
+ .333	16.8	M=17.5 in^{2}lbs/turn	M=2.79 in^{2}lbs/rad
+ .500	19.9		K=11.1 in'lbs
+ .667	22.9		
+ .833	25.5		
+ 1.000	28.7		
+ .833	21.8		
+ .667	18.4		
+ .500	15.2	M=18.5 in^{2}lbs/turn	M=2.93 in^{2}lbs/rad
+ .333	13.0		K=7.52 in'lbs
+ .167	11.1		
0	8.9		
- .167	7.5		
- .333	6.3		
- .500	5.2	M=6.08 in^{2}lbs/turn	M=0.966 in^{2}lbs/rad
- .667	4.1		K=8.52 in'lbs
- .833	3.6		
- 1.000	2.8		
- .833	5.7		
- .667	7.5		
- .500	9.5	M=11.5 in^{2}lbs/turn	M=1.82 in^{2}lbs/rad
- .333	11.0		K=14.8 in'lbs
- .167	12.3		
0	15.0		

Sample Yarn No. 8.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	9.1		
+ .167	11.2		
+ .333	12.6		
+ .500	14.5	M=9.75 in^2lbs/turn	M=1.55 in^2lbs/rad K=9.40 in'lbs
+ .667	16.1		
+ .833	17.5		
+ 1.000	18.9		
+ .833	15.2		
+ .667	13.0		
+ .500	10.9	M=11.2 in^2lbs/turn	M=1.77 in^2lbs/rad K=6.25 in'lbs
+ .333	9.4		
+ .167	8.1		
0	7.4		
- .167	6.3		
- .333	5.5		
- .500	5.0	M=4.14 in^2lbs/turn	M=0.658 in^2lbs/rad K=7.08 in'lbs
- .667	4.3		
- .833	3.5		
- 1.000	3.2		
- .833	4.6		
- .667	5.7		
- .500	7.0	M=7.35 in^2lbs/turn	M=1.17 in^2lbs/rad K=10.6 in'lbs
- .333	8.0		
- .167	9.4		
0	10.7		

Sample Yarn No. 9.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	8.6		
+ .167	10.7		
+ .333	12.4		
+ .500	14.1	M=10.2 in^2lbs/turn	M=1.62 in^2lbs/rad
+ .667	15.8		K=8.88 in'lbs
+ .833	17.5		
+ 1.000	18.8		
+ .833	14.7		
+ .667	12.1		
+ .500	10.1	M=11.7 in^2lbs/turn	M=1.86 in^2lbs/rad
+ .333	8.7		K=5.36 in'lbs
+ .167	7.6		
0	6.5		
- .167	5.5		
- .333	4.7		
- .500	4.1	M=3.92 in^2lbs/turn	M=0.623 in^2lbs/rad
- .667	3.6		K=6.22 in'lbs
- .833	3.0		
- 1.000	2.4		
- .833	3.7		
- .667	4.9		
- .500	5.9	M=6.96 in^2lbs/turn	M=1.11 in^2lbs/rad
- .333	6.9		K=9.40 in'lbs
- .167	8.1		
0	9.6		

Sample Yarn No. 10.

UPTWIST (TPI)	TORQUE (in-lbs $x10^6$)	TORQUE(10^6)=M(uptwist)+K	
0	8.5		
+ .167	10.3		
+ .333	12.1		
+ .500	13.8	M=10.5 in^2lbs/turn	M=1.67 in^2lbs/rad
+ .667	15.5		K=8.55 in'lbs
+ .833	17.3		
+ 1.000	19.1		
+ .833	14.7		
+ .667	12.2		
+ .500	10.2	M=12.0 in^2lbs/turn	M=1.91 in^2lbs/rad
+ .333	8.6		K=5.22 in'lbs
+ .167	7.6		
0	6.3		
- .167	5.5		
- .333	4.7		
- .500	4.1	M=3.70 in^2lbs/turn	M=0.568 in^2lbs/rad
- .667	3.6		K=6.13 in'lbs
- .833	3.2		
- 1.000	2.5		
- .833	3.7		
- .667	5.0		
- .500	6.2	M=7.09 in^2lbs/turn	M=1.13 in^2lbs/rad
- .333	7.3		K=9.64 in'lbs
- .167	8.1		
0	9.8		

Sample Yarn No. 11.

UPTWIST(TPI)	TORQUE(in-lbs $x10^6$)	TORQUE(10^6)=M(uptwist)+K	
0	10.1		
+ .167	12.7		
+ .333	14.5		
+ .500	17.1	M=12.4 in^2lbs/turn	M=1.97 in^2lbs/rad
+ .667	18.8		K=10.5 in'lbs
+ .833	20.7		
+ 1.000	22.6		
+ .833	17.6		
+ .667	14.5		
+ .500	12.4	M=13.9 in^2lbs/turn	M=2.22 in^2lbs/rad
+ .333	10.5		K=6.54 in'lbs
+ .167	9.2		
0	7.9		
- .167	6.5		
- .333	5.4		
- .500	4.7	M=4.82 in^2lbs/turn	M=0.767 in^2lbs/rad
- .667	4.2		K=7.42 in'lbs
- .833	3.5		
- 1.000	2.8		
- .833	4.1		
- .667	5.6		
- .500	6.8	M=8.10 in^2lbs/turn	M=1.29 in^2lbs/rad
- .333	8.3		K=10.9 in'lbs
- .167	9.5		
0	10.9		

Sample Yarn No. 11.

UPTWIST (TPI)	TORQUE (in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	10.1		
+ .167	12.7		
+ .333	14.5		
+ .500	17.1	M=12.4 in^{2}lbs/turn	M=1.97 in^{2}lbs/rad
+ .667	18.8		K=10.5 in'lbs
+ .833	20.7		
+ 1.000	22.6		
+ .833	17.6		
+ .667	14.5		
+ .500	12.4	M=13.9 in^{2}lbs/turn	M=2.22 in^{2}lbs/rad
+ .333	10.5		K=6.54 in'lbs
+ .167	9.2		
0	7.9		
- .167	6.5		
- .333	5.4		
- .500	4.7	M=4.82 in^{2}lbs/turn	M=0.767 in^{2}lbs/rad
- .667	4.2		K=7.42 in'lbs
- .833	3.5		
- 1.000	2.8		
- .833	4.1		
- .667	5.6		
- .500	6.8	M=8.10 in^{2}lbs/turn	M=1.29 in^{2}lbs/rad
- .333	8.3		K=10.9 in'lbs
- .167	9.5		
0	10.9		

Sample Yarn No. 12.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	11.5		
+ .167	14.9		
+ .333	17.5	M=14.1 in^{2}lbs/turn	M=2.25 in^{2}lbs/rad
+ .500	19.7		K=12.3 in'lbs
+ .667	22.2		
+ .833	23.9		
+ 1.000	25.9		
+ .833	19.7		
+ .667	16.0		
+ .500	13.4	M=16.2 in^{2}lbs/turn	M=2.57 in^{2}lbs/rad
+ .333	11.6		K=6.95 in'lbs
+ .167	9.9		
0	8.7		
- .167	7.3		
- .333	7.7		
- .500	5.4	M=5.28 in^{2}lbs/turn	M=0.84 in^{2}lbs/rad
- .667	4.9		K=8.58 in'lbs
- .833	4.0		
- 1.000	3.6		
- .833	5.4		
- .667	7.0		
- .500	8.4	M=9.49 in^{2}lbs/turn	M=1.51 in^{2}lbs/rad
- .333	9.9		K=13.2 in'lbs
- .167	11.5		
0	13.4		

Sample Yarn No. 13.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	14.2		
+ .167	18.5		
+ .333	21.7		
+ .500	25.4	M=20.2 in^2lbs/turn	M=3.21 in^2lbs/rad
+ .667	28.0		K=14.8 in'lbs
+ .883	31.6		
+ 1.000	34.8		
+ .833	25.9		
+ .667	21.0		
+ .500	17.4	M=23.2 in^2lbs/turn	M=3.69 in^2lbs/rad
+ .333	14.4		K=7.77 in'lbs
+ .167	12.0		
0	10.1		
- .167	8.6		
- .333	7.1		
- .500	6.1	M=6.12 in^2lbs/turn	M=0.973 in^2lbs/rad
- .667	5.5		K=9.62 in'lbs
- .833	4.6		
- 1.000	3.9		
- .833	5.5		
- .667	7.4		
- .500	9.2	M=1187 in^2lbs/turn	M=1.89 in^2lbs/rad
- .333	10.8		K=15.4 in'lbs
- .167	13.4		
0	16.0		

Sample Yarn No. 14.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	12.7		
+ .167	17.1		
+ .333	20.7		
+ .500	23.9	M=18.2 in^{2}lbs/turn	M=2.89 in^{2}lbs/rad
+ .667	26.6		K=13.6 in'lbs
+ .833	28.8		
+ 1.000	31.9		
+ .833	23.5		
+ .667	18.9		
+ .500	15.5	M=20.8 in^{2}lbs/turn	M=3.30 in^{2}lbs/rad
+ .333	13.2		K=7.29 in'lbs
+ .167	11.3		
0	9.5		
- .167	7.7		
- .333	6.4		
- .500	5.6	M=6.08 in^{2}lbs/turn	M=0.966 in^{2}lbs/rad
- .667	4.5		K=8.87 in'lbs
- .633	3.8		
- 1.000	3.3		
- .833	5.0		
- .667	7.2		
- .500	8.9	M=12.3 in^{2}lbs/turn	M=1.96 in^{2}lbs/rad
- .333	10.3		K=11.9 in'lbs
- .167	12.3		
0	14.5		

Sample Yarn No. 15.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	14.1		
+ .167	18.6		
+ .333	22.4		
+ .500	26.0	M=20.2 in^2lbs/turn	M=3.21 in^2lbs/rad
+ .667	29.2		K=15.1 in'lbs
+ .833	31.8		
+ 1.000	34.5		
+ .833	25.7		
+ .667	20.8		
+ .500	17.1	M=23.0 in^2lbs/turn	M=3.66 in^2lbs/rad
+ .333	14.3		K=7.67 in'lbs
+ .167	12.0		
0	9.9		
- .167	8.5		
- .333	7.0		
- .500	5.9	M=6.12 in^2lbs/turn	M=0.973 in^2lbs/rad
- .667	5.1		K=9.45 in'lbs
- .833	4.5		
- 1.000	3.7		
- .833	5.7		
- .667	7.8		
- .500	9.1	M=34.7 in^2lbs/turn	M=5.52 in^2lbs/rad
- .333	11.7		K=42.1 in'lbs
- .167	13.8		
0	15.8		

Sample Yarn 16.

UPTWIST(TPI)		TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
	0	10.4		
+	.167	13.6		
+	.333	16.7		
+	.500	19.6	M=16.9 in^2lbs/turn	M=2.69 in^2lbs/rad
+	.667	22.2		K=10.8 in'lbs
+	.833	24.8		
+	1.000	27.4		
+	.833	20.6		
+	.667	16.6		
+	.500	13.8	M=18.1 in^2lbs/turn	M=2.87 in^2lbs/rad
+	.333	11.7		K=6.38 in'lbs
+	.167	9.8		
	0	8.1		
-	.167	6.9		
-	.333	5.6		
-	.500	4.4	M=5.35 in^2lbs/turn	M=0.851 in^2lbs/rad
-	.667	3.9		K=7.67 in'lbs
-	.833	3.3		
-	1.000	2.8		
-	.833	4.4		
-	.667	5.7		
-	.500	6.8	M=9.51 in^2lbs/turn	M=1.51 in^2lbs/rad
-	.333	8.6		K=12.1 in'lbs
-	.167	10.3		
	0	12.6		

Sample Yarn No. 17.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	10.4		
+ .167	13.9		
+ .333	17.0	M=18.0 in^{2}lbs/turn	M=2.86 in^{2}lbs/rad
+ .500	20.1		K=10.8 in'lbs
+ .667	22.9		
+ .833	26.1		
+ 1.000	28.3		
+ .833	21.2		
+ .667	17.1		
+ .500	13.9	M=19.1 in^{2}lbs/turn	M=3.03 in^{2}lbs/rad
+ .333	11.6		K=6.16 in'lbs
+ .167	9.7		
0	8.1		
- .167	6.6		
- .333	5.4		
- .500	4.4	M=5.55 in^{2}lbs/turn	M=0.882 in^{2}lbs/rad
- .667	3.6		K=7.56 in'lbs
- .833	3.0		
- 1.000	2.5		
- .833	4.0		
- .667	5.3		
- .500	6.6	M=9.31 in^{2}lbs/turn	M=1.48 in^{2}lbs/rad
- .333	8.2		K=11.6 in'lbs
- .167	9.9		
0	12.0		

Sample Yarn No. 18.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	9.6		
+ .167	12.8		
+ .333	15.4		
+ .500	17.7	M=15.4 in^{2}lbs/turn	M=2.45 in^{2}lbs/rad
+ .667	20.4		K=10.0 in'lbs
+ .833	22.8		
+ 1.000	25.1		
+ .833	18.9		
+ .667	15.5		
+ .500	12.8	M=16.5 in^{2}lbs/turn	M=2.63 in^{2}lbs/rad
+ .333	10.8		K=5.99 in'lbs
+ .167	9.1		
0	7.5		
- .167	6.2		
- .333	5.2		
- .500	4.5	M=4.91 in^{2}lbs/turn	M=0.781 in^{2}lbs/rad
- .667	3.8		K=7.14 in'lbs
- .833	3.1		
- 1.000	2.4		
- .833	4.0		
- .667	5.3		
- .500	6.6	M=9.27 in^{2}lbs/turn	M=1.47 in^{2}lbs/rad
- .333	8.0		K=11.5 in'lbs
- .167	10.1		
0	11.9		

Sample Yarn No. 19.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	11.0		
+ .167	14.0		
+ .333	17.4		
+ .500	20.3	M=17.9 in^2lbs/turn	M=2.85 in^2lbs/rad
+ .667	23.1		K=11.2 in'lbs
+ .833	26.2		
+ 1.000	29.0		
+ .833	21.8		
+ .667	17.4		
+ .500	14.2	M=19.3 in^2lbs/turn	M=3.06 in^2lbs/rad
+ .333	12.2		K=6.54 in'lbs
+ .167	10.1		
0	8.5		
- .167	7.0		
- .333	5.9		
- .500	5.0	M=5.51 in^2lbs/turn	M=0.875 in^2lbs/rad
- .667	4.3		K=8.04 in'lbs
- .833	3.5		
- 1.000	2.9		
- .833	4.2		
- .667	5.8		
- .500	7.2	M=9.51 in^2lbs/turn	M=1.51 in^2lbs/rad
- .333	8.7		K=12.1 in'lbs
- .167	10.6		
0	12.4		

Sample Yarn No. 20.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	10.8		
+ .167	14.1		
+ .333	16.9		
+ .500	19.8	M=16.7 in^{2}lbs/turn	M=2.65 in^{2}lbs/rad
+ .667	22.3		K=11.1 in'lbs
+ .833	24.8		
+ 1.000	27.8		
+ .833	21.1		
+ .667	17.6		
+ .500	14.1	M=18.5 in^{2}lbs/turn	M=2.94 in^{2}lbs/rad
+ .333	11.7		K=6.57 in'lbs
+ .167	10.0		
0	8.4		
- .167	6.8		
- .333	5.5		
- .500	4.6	M=6.10 in^{2}lbs/turn	M=0.970 in^{2}lbs/rad
- .667	3.7		K=7.90 in'lbs
- .833	2.8		
- 1.000	2.1		
- .833	3.8		
- .667	5.4		
- .500	7.2	M=10.6 in^{2}lbs/turn	M=1.69 in^{2}lbs/rad
- .333	9.1		K=12.6 in'lbs
- .167	11.0		
0	12.6		

Sample Yarn No. 21.

UPTWIST(TPI)	TORQUE(in-lbs $x10^6$)	TORQUE(10^6)=M(uptwist)+K	
0	10.2		
+ .167	12.9		
+ .333	15.8		
+ .500	17.9	M=15.7 in^2 lbs/turn	M=2.50 in^2 lbs/rad
+ .667	20.2		K=10.1 in'lbs
+ .833	23.4		
+ 1.000	25.9		
+ .833	19.6		
+ .667	16.4		
+ .500	13.9	M=15.8 in^2 lbs/turn	M=2.51 in^2 lbs/rad
+ .333	12.1		K=7.47 in'lbs
+ .167	10.3		
0	9.1		
- .167	8.1		
- .333	7.4		
- .500	6.6	M=4.18 in^2 lbs/turn	M=0.665 in^2 lbs/rad
- .667	5.8		K=8.84 in'lbs
- .833	5.4		
- 1.000	5.0		
- .833	6.3		
- .667	7.7		
- .500	9.1	M=8.76 in^2 lbs/turn	M=1.39 in^2 lbs/rad
- .333	10.5		K=13.6 in'lbs
- .167	12.3		
0	13.7		

Sample Yarn No. 22.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	12.3		
+ .167	15.6		
+ .333	19.1		
+ .500	21.6	M=16.7 in^2lbs/turn	M=2.66 in^2lbs/rad
+ .667	24.4		K=12.9 in'lbs
+ .833	26.7		
+ 1.000	29.1		
+ .833	21.6		
+ .667	18.0		
+ .500	15.1	M=18.7 in^2lbs/turn	M=2.98 in^2lbs/rad
+ .333	12.6		K=7.23 in'lbs
+ .167	10.7		
0	9.1		
- .167	7.6		
- .333	6.6		
- .500	5.8	M=4.98 in^2lbs/turn	M=0.791 in^2lbs/rad
- .667	5.1		K=8.59 in'lbs
- .833	4.5		
- 1.000	3.9		
- .833	5.7		
- .667	7.4		
- .500	8.8	M=10.3 in^2lbs/turn	M=1.64 in^2lbs/rad
- .333	10.6		K=14.2 in'lbs
- .167	12.2		
0	14.5		

Sample Yarn No. 24.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	9.4		
+ .167	11.5		
+ .333	13.6		
+ .500	14.3	M=8.54 in^2lbs/turn	M=1.36 in^2lbs/rad
+ .667	15.8		K=9.98 in'lbs
+ .833	16.8		
+ 1.000	18.4		
+ .833	15.2		
+ .667	13.0		
+ .500	11.3	M=10.5 in^2lbs/turn	M=1.66 in^2lbs/rad
+ .333	9.8		K=6.74 in'lbs
+ .167	8.6		
0	7.5		
- .167	6.5		
- .333	6.0		
- .500	5.3	M=3.46 in^2lbs/turn	M=0.550 in^2lbs/rad
- .667	4.8		K=7.22 in'lbs
- .833	4.4		
- 1.000	4.0		
- .833	5.1		
- .667	6.3		
- .500	7.3	M=7.07 in^2lbs/turn	M=1.12 in^2lbs/rad
- .333	8.4		K=11.0 in'lbs
- .167	9.8		
0	11.1		

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Sample Yarn No. 25.

UPTWIST (TPI)	TORQUE (in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	13.5		
+ .167	17.2		
+ .333	20.3		
+ .500	23.3	M=17.3 in^{2}lbs/turn	M=2.75 in^{2}lbs/rad
+ .667	26.1		K=14.2 in'lbs
+ .833	28.5		
+ 1.000	30.9		
+ .833	24.6		
+ .667	20.0		
+ .500	16.1	M=20.4 in^{2}lbs/turn	M=3.25 in^{2}lbs/rad
+ .333	13.5		K=7.89 in'lbs
+ .167	12.0		
0	9.7		
- .167	8.5		
- .333	7.3		
- .500	6.4	M=5.35 in^{2}lbs/turn	M=.851 in^{2}lbs/rad
- .667	5.7		K=9.33 in'lbs
- .833	4.9		
- 1.000	4.3		
- .833	6.1		
- .667	7.8		
- .500	9.6	M=11.9 in^{2}lbs/turn	M=1.89 in^{2}lbs/rad
- .333	11.9		K=15.9 in'lbs
- .167	14.0		
0	16.1		

Sample Yarn No. 26.

UPTWIST(TPI)	TORQUE(in-lbs $\times 10^6$)	TORQUE(10^6)=M(uptwist)+K	
0	11.6		
+ .167	13.4		
+ .333	15.6		
+ .500	16.6	M=15.8 in^{2}lbs/turn	M=2.51 in^{2}lbs/rad
+ .667	18.4		K=12.8 in'lbs
+ .833	21.1		
+ 1.000	21.5		
+ .833	18.6		
+ .667	15.5		
+ .500	13.2	M=18.1 in^{2}lbs/turn	M=2.88 in^{2}lbs/rad
+ .333	11.8		K=7.63 in'lbs
+ .167	10.4		
0	9.6		
- .167	8.6		
- .333	7.7		
- .500	6.9	M=4.80 in^{2}lbs/turn	M=0.763 in^{2}lbs/rad
- .667	6.2		K=9.31 in'lbs
- .833	5.7		
- 1.000	5.2		
- .833	6.7		
- .667	8.0		
- .500	9.1	M=7.66 in^{2}lbs/turn	M=1.22 in^{2}lbs/rad
- .333	10.9		K=12.8 in'lbs
- .167	12.2		
0	13.1		

Sample Yarn No. 27.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	12.2		
+ .167	15.9		
+ .333	18.3		
+ .500	20.8	M=10.9 in^{2}lbs/turn	M=1.73 in^{2}lbs/rad
+ .667	23.5		K=10.7 in'lbs
+ .833	25.8		
+ 1.000	28.3		
+ .833	22.1		
+ .667	18.1		
+ .500	15.0	M=12.5 in^{2}lbs/turn	M=1.98 in^{2}lbs/rad
+ .333	12.8		K=7.32 in'lbs
+ .167	10.9		
0	9.4		
- .167	8.3		
- .333	7.8		
- .500	7.0	M=3.59 in^{2}lbs/turn	M=0.571 in^{2}lbs/rad
- .667	6.0		K=8.11 in'lbs
- .833	5.2		
- 1.000	4.7		
- .833	6.3		
- .667	7.7		
- .500	9.2	M=7.66 in^{2}lbs/turn	M=1.22 in^{2}lbs/rad
- .333	11.0		K=12.4 in'lbs
- .167	12.7		
0	14.1		

Sample Yarn No. 28.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	10.5		
+ .167	12.6		
+ .333	14.2		
+ .500	16.4	M=21.8 in^{2}lbs/turn	M=3.46 in^{2}lbs/rad
+ .667	18.1		K=14.6 in'lbs
+ .833	19.7		
+ 1.000	21.4		
+ .833	17.5		
+ .667	14.5		
+ .500	12.4	M=23.3 in^{2}lbs/turn	M=3.71 in^{2}lbs/rad
+ .333	11.0		K=9.02 in'lbs
+ .167	9.6		
0	8.4		
- .167	7.5		
- .333	6.7		
- .500	6.1	M=7.00 in^{2}lbs/turn	M=1.11 in^{2}lbs/rad
- .667	5.7		K=10.1 in'lbs
- .833	5.1		
- 1.000	4.8		
- .833	6.0		
- .667	7.2		
- .500	8.4	M=13.5 in^{2}lbs/turn	M=2.15 in^{2}lbs/rad
- .333	9.8		K=16.6 in'lbs
- .167	11.1		
0	12.4		

Sample Yarn No. 29.

UPTWIST (TPI)	TORQUE (in-lbs $\times 10^6$)	TORQUE(10^6)=M(uptwist)+K	
0	13.7		
+ .167	18.9		
+ .333	22.2		
+ .500	25.5	M=13.4 in^2lbs/turn	M=2.13 in^2lbs/rad
+ .667	30.0		K=12.4 in'lbs
+ .833	33.0		
+ 1.000	35.5		
+ .833	27.2		
+ .667	22.8		
+ .500	19.4	M=15.6 in^2lbs/turn	M=2.48 in^2lbs/rad
+ .333	16.1		K=7.73 in'lbs
+ .167	13.0		
0	10.9		
- .167	9.0		
- .333	7.1		
- .500	6.1	M=5.20 in^2lbs/turn	M=0.826 in^2lbs/rad
- .667	5.2		K=8.50 in'lbs
- .883	4.4		
- 1.000	3.6		
- .833	5.4		
- .667	7.4		
- .500	9.2	M=10.6 in^2lbs/turn	M=1.69 in^2lbs/rad
- .333	11.4		K=14.2 in'lbs
- .167	14.1		
0	17.5		

Sample Yarn No. 30.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	11.7		
+ .167	14.8		
+ .333	17.2		
+ .500	19.4	M=22.0 in^{2}lbs/turn	M=3.50 in^{2}lbs/rad
+ .667	21.6		K=13.5 in'lbs
+ .833	23.3		
+ 1.000	25.4		
+ .833	20.4		
+ .667	16.5		
+ .500	14.3	M=24.3 in^{2}lbs/turn	M=3.86 in^{2}lbs/rad
+ .333	12.5		K=7.18 in'lbs
+ .167	10.7		
0	8.9		
- .167	7.5		
- .333	6.5		
- .500	5.7	M=6.01 in^{2}lbs/turn	M=0.956 in^{2}lbs/rad
- .667	4.9		K=9.09 in'lbs
- .833	4.1		
- 1.000	3.6		
- .833	5.5		
- .667	7.5		
- .500	8.3	M=12.0 in^{2}lbs/turn	M=1.90 in^{2}lbs/rad
- .333	10.7		K=15.2 in'lbs
- .167	12.2		
0	14.6		

Sample Yarn No. 31.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	13.2		
+ .167	17.0		
+ .333	21.1		
+ .500	25.1	M=11.6 in^2lbs/turn	M=1.84 in^2lbs/rad
+ .667	28.8		K=10.6 in'lbs
+ .833	30.8		
+ 1.000	35.7		
+ .833	26.3		
+ .667	20.3		
+ .500	17.0	M=13.5 in^2lbs/turn	M=2.14 in^2lbs/rad
+ .333	14.6		K=6.42 in'lbs
+ .167	11.7		
0	9.6		
- .167	8.1		
- .333	6.8		
- .500	5.7	M=4.25 in^2lbs/turn	M=0.676 in^2lbs/rad
- .667	4.7		K=7.63 in'lbs
- .833	4.1		
- 1.000	3.6		
- .833	5.2		
- .667	7.2		
- .500	9.0	M=7.95 in^2lbs/turn	M=1.26 in^2lbs/rad
- .333	11.1		K=11.5 in'lbs
- .167	13.4		
0	15.5		

Sample Yarn 32.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	10.5		
+ .167	12.5		
+ .333	14.5		
+ .500	16.3	M=17.6 in^2lbs/turn	M=2.80 in^2lbs/rad
+ .667	18.4		K=13.5 in'lbs
+ .833	20.3		
+ 1.000	22.0		
+ .833	17.1		
+ .667	14.2		
+ .500	11.8	M=20.6 in^2lbs/turn	M=3.27 in^2lbs/rad
+ .333	10.1		K=7.34 in'lbs
+ .167	8.8		
0	7.9		
- .167	6.9		
- .333	6.1		
- .500	5.3	M=5.68 in^2lbs/turn	M=0.903 in^2lbs/rad
- .667	4.7		K=9.09 in'lbs
- .833	4.1		
- 1.000	3.6		
- .833	5.0		
- .667	6.1		
- .500	7.5	M=11.7 in^2lbs/turn	M=1.87 in^2lbs/rad
- .333	8.7		K=15.2 in'lbs
- .167	10.3		
0	11.6		

Sample Yarn No. 33.

UPTWIST(TPI)	TORQUE(in-lbs x10^6)	TORQUE(10^6)=M(uptwist)+K	
0	12.9		
+ .167	16.6		
+ .333	19.8		
+ .500	22.6	M=21.6 in^{2}lbs/turn	M=3.43 in^{2}lbs/rad
+ .667	25.3		K=14.0 in'lbs
+ .833	28.4		
+ 1.000	30.7		
+ .833	23.4		
+ .667	19.9		
+ .500	16.3	M=23.2 in^{2}lbs/turn	M=3.69 in^{2}lbs/rad
+ .333	13.0		K=7.96 in'lbs
+ .167	10.9		
0	9.3		
- .167	8.2		
- .333	7.1		
- .500	6.1	M=6.50 in^{2}lbs/turn	M=1.03 in^{2}lbs/rad
- .667	5.0		K=9.84 in'lbs
- .833	4.3		
- 1.000	3.7		
- .833	5.7		
- .667	7.0		
- .500	8.8	M=12.1 in^{2}lbs/turn	M=1.93 in^{2}lbs/rad
- .333	11.0		K=15.6 in'lbs
- .167	13.3		
0	15.6		

APPENDIX B

Torque-Uptwist-Downtwist-Uptwist Results: Laboratory Yarns

Identification Code Number	Rotor Speed RPM	Combing Roller Speed RPM	Yarn Number Cotton Count	Yarn Number Denier	T.P.I.	T.M.	Fiber Type
1	25593	5000	14.3	373	11.7	3.11	cotton
2	25593	6000	14.0	380	11.6	3.11	cotton
3	25593	7000	13.8	385	11.6	3.13	cotton
4	25593	8000	14.0	380	11.6	3.09	cotton
5	25593	9000	14.3	371	11.7	3.09	cotton
6	28875	5000	16.4	324	13.2	3.24	cotton
7	28875	6000	13.8	387	12.2	3.30	cotton
8	28875	7000	16.5	322	12.7	3.13	cotton
9	28875	8000	16.1	330	13.0	3.25	cotton
10	28875	9000	16.5	323	13.3	3.27	cotton
11	31500	5000	16.3	327	13.9	3.44	cotton
12	31500	6000	13.9	384	14.0	3.77	cotton
13	31500	7000	13.8	387	14.3	3.87	cotton
14	31500	8000	13.7	389	12.6	3.42	cotton
15	31500	9000	13.7	387	14.1	3.81	cotton
16	28875	5000	13.5	393	12.6	3.44	cotton
17	28875	7000	14.0	380	12.5	3.35	cotton
18	28875	8000	14.3	371	12.8	3.38	cotton
19	28875	9000	13.8	385	12.7	3.43	cotton
20	31500	5000	14.5	366	14.0	3.68	cotton
21	26970	7000	14.1	377	13.8	3.68	35% cot/65% poly
22	26970	8000	14.0	379	14.6	3.89	35% cot/65% poly
23	28970	9000	14.3	373	14.2	3.76	35% cot/65% poly
24	31500	7000	16.6	321	14.3	3.51	35% cot/65% poly
25	31500	7000	14.4	368	14.0	3.68	35% cot/65% poly
26	31500	8000	14.0	380	14.3	3.83	35% cot/65% poly
27	31500	9000	16.7	319	14.3	3.51	35% cot/65% poly
28	31500	9000	14.0	381	13.8	3.70	35% cot/65% poly
29	32913	8000	16.1	331	14.1	3.51	35% cot/65% poly
30	32913	8000	14.1	378	14.0	3.74	35% cot/65% poly
31	32913	9000	16.2	329	14.5	3.62	35% cot/65% poly
32	32913	9000	14.5	366	15.1	3.96	35% cot/65% poly
33	32913	7000	14.1	378	14.3	3.82	35% cot/65% poly
34	commercial ring spun		9.6	552	11.1	3.57	cotton
35	commercial open end spun		9.7	547	12.0	3.85	cotton

YARN DESCRIPTION : Yarn Sample No. 1.

yarn type - 100% cotton
combing roller speed - 5000 RPM
rotor speed - 25593 RPM
cotton count - 14.26 (373 D)
T.P.I. 11.73
T.M. 3.11

GPD	TORQUE(in-lbs x10^6)
.01	9.4
.06	43.6
.09	56.4
.12	74.7
.14	86.2

LINEAR REGRESSION

TORQUE(10^6in-lbs)=581(GPD)+5.25

YARN DESCRIPTION : Sample Yarn No. 2.

yarn type - 100% cotton
combing roller speed - 6000 RPM
rotor speed - 25593 RPM
cotton count - 13.99 (380 D)
T.P.I. 11.62
T.M. 3.02

GPD	TORQUE(in-lbs x10^6)
.01	8.5
.06	42.3
.08	54.7
.11	73.1
.14	84.0

LINEAR REGRESSION

TORQUE(10^6in-lbs)=591(GPD)+5.24

YARN DESCRIPTION : Sample Yarn No. 3.

yarn type - 100% cotton
combing roller speed - 7000 RPM
rotor speed - 25593 RPM
cotton count - 13.82 (385 D)
T.P.I. 11.63
T.M. 3.13

GPD	TORQUE(in-lbs x10^6)
.01	6.7
.06	43.6
.08	56.3
.11	73.9
.14	85.6

LINEAR REGRESSION

TORQUE(10^6in-lbs)=613(GPD)+4.14

YARN DESCRIPTION : Sample Yarn No. 4.

yarn type - 100% cotton
combing roller speed - 8000 RPM
rotor speed - 25593 RPM
cotton count - 13.99 (380 D)
T.P.I 11.56
T.M. 3.09

GPD	TORQUE(in-lbs x10^6)
.01	10.3
.06	42.1
.08	54.2
.11	70.4
.14	83.2

LINEAR REGRESSION

TORQUE(10^6in-lbs)=565(GPD)+6.81

YARN DESCRIPTION : Sample Yarn No. 5.

yarn type - 100% cotton
combing roller speed - 9000 RPM
rotor speed - 25593 RPM
cotton count - 14.31 (371 D)
T.P.I. 11.71
T.M. 3.09

GPD	TORQUE(in-lbs x10^6)
.01	7.2
.06	39.7
.09	51.3
.12	69.1
.14	80.0

LINEAR REGRESSION

TORQUE(10^6in-lbs)=550(GPD)+3.23

YARN DESCRIPTION : Sample Yarn No. 6.

yarn type - 100% cotton
combing roller speed - 5000 RPM
rotor speed - 28875 RPM
cotton count - 16.43 (324 D)
T.P.I. 13.15
T.M. 3.24

GPD	TORQUE(in-lbs x10^6)
.01	8.6
.07	35.2
.10	45.8
.13	60.2
.16	71.4

LINEAR REGRESSION

TORQUE(10^6in-lbs)=419(GPD)+4.81

YARN DESCRIPTION : Sample Yarn No. 7.

yarn type - 100% cotton
combing roller speed - 6000 RPM
rotor speed - 28875 RPM
cotton count - 13.75 (387 D)
T.P.I. 12.24
T.M. 3.30

GPD	TORQUE(in-lbs $\times 10^6$)
.01	10.9
.06	39.7
.08	51.4
.11	67.6
.14	79.9

LINEAR REGRESSION

TORQUE(10^6in-lbs)=537(GPD)+6.88

YARN DESCRIPTION : Sample Yarn No. 8

yarn type - 100% cotton
combing roller speed - 7000 RPM
rotor speed - 28875 RPM
coton count - 16.49's (322 D)
T.P.I. 12.72
T.M. 3.13

GPD	TORQUE(in-lbs $\times 10^6$)
.01	9.1
.07	35.0
.10	45.6
.13	60.9
.16	71.3

LINEAR REGRESSION

TORQUE(10^6in-lbs)=418(GPD)+5.09

YARN DESCRIPTION: Sample Yarn No. 9.

yarn type - 100% cotton
combing roller speed - 8000 RPM
rotor speed - 28875 RPM
cotton count - 16.13's (330 D)
T.P.I. 13.04
T.M. 3.25

GPD	TORQUE(in-lbs $\times 10^6$)
.01	8.6
.07	33.4
.10	44.5
.13	59.2
.16	67.3

LINEAR REGRESSION

TORQUE(10^6in-lbs)=399(GPD)+5.08

YARN DESCRIPTION : Sample Yarn No. 10.

yarn type - 100% cotton
combing roller speed - 9000 RPM
rotor speed - 28875 RPM
cotton count - 16.46 (323 D)
T.P.I. 13.27
T.M. 3.27

GPD	TORQUE(in-lbs x10^6)
.01	8.5
.07	33.5
.10	45.2
.13	60.4
.16	71.3

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=423(GPD)+4.02

YARN DESCRIPTION ; Sample Yarn No. 11.

yarn type - 100% cotton
combing roller speed - 5000 RPM
rotor speed - 31500 RPM
cotton count - 16.26 (327 D)
T.P.I. 13.86
T.M. 3.44

GPD	TORQUE(in-lbs x10^6)
.01	10.1
.07	36.7
.10	48.8
.13	65.0
.16	75.8

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=443(GPD)+5.60

YARN DESCRIPTION : Sample Yarn No. 12.

yarn type - 100% cotton
combing roller speed 6000 RPM
rotor speed - 31500 RPM
cotton count - 13.85 (384 D)
T.P.I. 14.03
T.M. 3.77

GPD	TORQUE(in-lbs x10^6)
.01	11.5
.06	44.0
.09	58.0
.11	79.3
.14	92.3

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=632(GPD)+5.22

YARN DESCRIPTION : Sample Yarn No. 13.

yarn description		GPD	TORQUE(in-lbs $x10^6$)
yarn type - 100% cotton		.01	14.2
combing roller speed -	7000 RPM	.06	44.3
rotor speed -	31500 RPM	.09	57.9
cotton count - 13.75	(387 D)	.11	78.0
T.P.I. 14.33		.14	90.9
T.M. 3.87			

LINEAR REGRESSION

TORQUE(10^6in-lbs)=599(GPD)+7.91

YARN DESCRIPTION : Sample Yarn No. 14.

yarn description		GPD	TORQUE(in-lbs $x10^6$)
yarn type - 100% cotton		.01	12.7
combing roller speed -	8000 RPM	.06	45.8
rotor speed -	31500 RPM	.08	60.8
cotton count - 13.66	(389 D)	.11	83.5
T.P.I. 12.64		.13	96.1
T.M. 3.42			

LINEAR REGRESSION

TORQUE(10^6in-lbs)=703(GPD)+4.94

YARN DESCRIPTION : Sample Yarn No. 15.

yarn description		GPD	TORQUE(in-lbs $x10^6$)
yarn type - 100% cotton		.01	14.1
combing roller speed -	9000 RPM	.06	45.2
rotor speed -	31500 RPM	.09	59.2
cotton count - 13.73	(387 D)	.11	81.0
T.P.I. 14.10		.14	94.4
T.M. 3.81			

LINEAR REGRESSION

TORQUE(10^6in-lbs)=628(GPD)+7.26

YARN DESCRIPTION: **Sample Yarn No. 16.**

yarn type - 100% cotton
combing roller speed - 5000 RPM
rotor speed - 28875 RPM
cotton count - 13.52 (393 D)
T.P.I. 12.64
T.M. 3.44

GPD	TORQUE(in-lbs $x10^6$)
.01	10.4
.06	46.4
.08	60.4
.11	78.6
.13	93.0

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=683(GPD)+4.48

YARN DESCRIPTION: **Sample Yarn No. 17.**

yarn type - 100% cotton
combing roller speed - 7000 RPM
rotor speed - 28875 RPM
cotton count - 13.99 (380 D)
T.P.I. 12.51
T.M. 3.35

GPD	TORQUE(in-lbs $x10^6$)
.01	10.4
.06	46.9
.08	60.5
.11	75.5
.14	93.5

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=634(GPD)+6.67

YARN DESCRIPTION: **Sample Yarn No. 18.**

yarn type - 100% cotton
combing roller speed - 8000 RPM
rotor speed - 28875 RPM
cotton count - 14.34 (371 D)
T.P.I. 12.81
T.M. 3.38

GPD	TORQUE(in-lbs $x10^6$)
.01	9.6
.06	45.8
.09	63.1
.12	77.1
.14	87.1

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=591(GPD)+6.86

YARN DESCRIPTION: Sample Yarn No. 19.

yarn type - 100% cotton
combing roller speed - 9000 RPM
rotor speed - 28875 RPM
cotton count - 13.82 (385 D)
T.P.I. 12.74
T.M. 3.43

GPD	TORQUE(in-lbs $\times 10^6$)
.01	11.0
.06	48.0
.08	62.3
.11	81.9
.14	95.8

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=661(GPD)+6.94

YARN DESCRIPTION : Sample Yarn No. 20.

yarn type - 100% cotton
combing roller speed - 5000 RPM
rotor speed - 31500 RPM
cotton count - 14.54 (366 D)
T.P.I. 14.04
T.M. 3.68

GPD	TORQUE(in-lbs $\times 10^6$)
.01	10.8
.06	48.4
.09	63.8
.12	82.9
.14	97.7

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=654(GPD)+5.80

YARN DESCRIPTION : Sample Yarn No. 21.

yarn type - 35/65 cotton polyester
combing roller speed - 7000 RPM
rotor speed - 28970 RPM
cotton count - 14.09 (377 D)
T.P.I. 13.80
T.M. 3.68

GPD	TORQUE(in-lbs $\times 10^6$)
.01	10.2
.06	44.9
.09	56.3
.11	84.2
.14	94.9

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=667(GPD)+3.41

YARN DESCRIPTION: Sample Yarn No. 22.

yarn type - 35/65 cotton-polyester
combing roller speed - 8000 RPM
rotor speed - 28970 RPM
cotton count - 14.01 (379 D)
T.P.I. 14.55
T.M. 3.89

GPD	TORQUE(in-lbs x10^6)
.01	12.3
.06	47.9
.08	62.8
.11	87.7
.14	95.6

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=668(GPD)+7.81

YARN DESCRIPTION: Sample Yarn No. 23.

yarn type - 35/65 cotton-polyester
combing roller speed - 9000 RPM
rotor speed - 28970 RPM
cotton count 14.26 (373 D)
T.P.I. 14.22
T.M. 3.76

GPD	TORQUE(in-lbs x10^6)
.01	13.1
.06	49.1
.09	61.0
.12	81.7
.14	95.9

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=621(GPD)+8.02

YARN DESCRIPTION: Sample Yarn No. 24.

yarn type 35/65 cotton-polyester
combing roller speed - 7000 RPM
rotor speed - 31500 RPM
cotton count - 16.56 (321 D)
T.P.I. 14.29
T.M. 3.51

GPD	TORQUE(in-lbs x10^6)
.01	9.4
.07	41.9
.10	51.5
.13	74.4
.16	83.5

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=503(GPD)+4.84

YARN DESCRIPTION : Sample Yarn No. 25.

yarn type 35/65 cotton-polyester
combing roller speed - 7000 RPM
rotor speed - 31500 RPM
cotton count - 14.44 (368 D)
T.P.I. 14.00
T.M. 3.68

GPD	TORQUE(in-lbs $x10^6$)
.01	13.5
.06	51.6
.09	66.7
.12	87.9
.14	99.5

LINEAR REGRESSION

TORQUE(10^6in-lbs)=656(GPD)+8.75

YARN DESCRIPTION : Sample Yarn No. 26.

yarn type 35/65 cotton-polyester
combing roller speed - 8000 RPM
rotor speed - 315000 RPM
cotton count - 13.99 (380 D)
T.P.I. 14.31
T.M. 3.83

GPD	TORQUE(in-lbs $x10^6$)
.01	12.2
.06	47.1
.08	62.6
.11	83.6
.14	98.8

LINEAR REGRESSION

TORQUE(10^6in-lbs)=678(GPD)+6.66

YARN DESCRIPTION : Sample Yarn No. 27.

yarn type 35/65 cotton-polyester
combing roller speed - 9000 RPM
rotor speed - 35100 RPM
cotton count - 16.66 (319 D)
T.P.I. 14.33
T.M. 3.51

GPD	TORQUE (in-lbs $x10^6$)
.01	10.5
.07	45.6
.10	58.8
.14	77.3
.16	91.3

LINEAR REGRESSION

TORQUE(10^6in-lbs)=523 (GPD)+6.45

YARN DESCRIPTION : Sample Yarn No. 28.

yarn type - 35/65 cotton-polyester
combing roller speed - 9000 RPM
rotor speed - 31500 RPM
cotton count - 13.97 (381 D)
T.P.I. 13.82
T.M. 3.70

GPD	TORQUE(in-lbs $\times 10^6$)
.01	13.7
.06	53.5
.08	66.0
.11	90.1
.14	102.0

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=693(GPD)+9.60

YARN DESCRIPTION : Sample Yarn No. 29.

yarn type - 35/65 cotton-polyester
combing roller speed - 8000 RPM
rotor speed - 32913 RPM
cotton count - 16.07 (331 D)
T.P.I. 14.09
T.M. 3.51

GPD	TORQUE(in-lbs $\times 10^6$)
.01	11.7
.07	46.4
.10	58.2
.13	75.8
.16	89.6

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=518(GPD)+7.68

YARN DESCRIPTION : Sample Yarn No. 30.

yarn type - 35/65 cotton-polyester
combing roller speed - 8000 RPM
rotor speed - 32913 RPM
cotton count - 14.06 (378 D)
T.P.I. 14.01
T.M. 3.74

GPD	TORQUE(in-lbs $\times 10^6$)
.01	13.2
.06	49.7
.08	63.5
.11	81.9
.14	96.8

LINEAR REGRESSION

TORQUE(10^6 in-lbs)=648(GPD)+9.21

YARN DESCRIPTION : Sample Yarn No. 31.

yarn description		GPD	TORQUE(in-lbs x10^6)
yarn type - 35/65 cotton-polyester		.01	10.5
combing roller speed - 9000 RPM		.07	45.4
rotor speed -	32913 RPM	.10	56.4
cotton count - 16.16	(329 D)	.13	71.1
T.P.I.	14.54	.16	85.5
T.M.	3.62		

LINEAR REGRESSION

TORQUE(10^6in-lbs)=493(GPD)+7.44

YARN DESCRIPTION : Sample Yarn No. 32.

yarn description		GPD	TORQUE(in-lbs x10^6)
yarn type - 35/65 cotton-polyester		.01	12.9
combing roller speed - 9000 RPM		.06	50.8
rotor speed -	32913 RPM	.09	67.0
cotton count - 14.54	(366 D)	.12	86.9
T.P.I.	15.1	.14	101.5
T.M.	3.96		

LINEAR REGRESSION

TORQUE(10^6in-lbs)=669(GPD)+7.62

YARN DESCRIPTION : Sample Yarn No. 33.

yarn description		GPD	TORQUE(in-lbs x10^6)
yarn type - 35/65 cotton-polyester		.01	13.7
combing roller speed - 7000 RPM		.06	53.7
rotor speed -	32913 RPM	.08	66.4
cotton count - 14.06	(378 D)	.11	84.9
T.P.I.	14.34	.14	93.8
T.M.	3.82		

LINEAR REGRESSION

TORQUE(10^6in-lbs)=625(GPD)+12.52

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